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## Fire Research Note No 970

FOAM BRANCHPIPE DESIGN

by

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# FIRE RESEARCH STATION

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### SUMMARY

An experimental model branchpipe, with a capacity of 5 l/min (1.1 g/min) of liquid, was used to investigate how the branchpipe configuration affects performance. The expansions, 25 per cent drainage times, shear stresses, and jet throws, of the foams were measured. A representative range of foam liquids was used and concentration and supply pressure varied. Some principles of design were determined. The model was compared with larger branchpipes.

A specific design for a 5 l/min branchpipe, which is simple to construct, and has good characteristics, is described.

NOTE. This branchpipe could be used as a laboratory reference standard and for the convenience of those who may wish to use it for this purpose, engineering drawings and a recommended test procedure, are being issued as a separate Fire Research Note No.971

KEY WORDS: Branchpipe, Foam

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### INTRODUCTION

Foam liquid purchases in the United Kingdom are made on the basis of Defence Standard 42-3<sup>1</sup>. The Defence Standard requires the use of a specific 227 l/min (50 gal/min) branchpipe, designated a No.2 branchpipe. This branchpipe is no longer manufactured. Those available have suffered deterioration from fair wear and tear over many years; and close reproducibility of results at different centres conducting Defence Standard tests is difficult to ensure. The No.2 branchpipe has a number of engineering features which make it expensive to produce and difficult to ensure precise uniformity and resistance to damage in use. A replacement branchpipe for the Defence Standard test is desirable. It should be simple to produce to precise dimensions, sufficiently robust to maintain its standard quality in routine use, and it should produce foam similar to that from No.2 branchpipe, which was selected because of its good foam making characteristics<sup>2</sup>.

Recent research<sup>3</sup> has shown that the Defence Standard test does not provide an adequate evaluation when the newer foam liquids are being examined and that the method would be improved if the foam was applied forcibly to the test fire, instead of gently to the surface. A very small foam branchpipe, which could be used on laboratory size fires would assist in achieving this objective.

During the past twenty years much research has been done on the formulation of foam liquids. Although it has been shown that the properties of a foam which can be changed by the equipment used to produce the foam<sup>4,5,6</sup>, can materially affect the fire suppression performance, little research has concerned foam making equipment in the low expansion category. Branchpipes in practical use, made by different manufacturers, vary widely in the quality of the foam they produce. Knowledge of how design details affect the performance of a branchpipe is desirable to correct this situation and establish a control basis for branchpipe performance to supplement foam liquid quality control. Such knowledge may also assist in the design of very large monitors, which have recently been introduced, and which, because of their very large size permit experimentation on only a very limited scale.

Preliminary consideration of these problems revealed that the numerous variables in branchpipe design and testing result in very large numbers of tests and that initial investigation should therefore be on the smallest practical scale. This would also fulfil the objective of designing a small branchpipe suitable for use on laboratory fires.

#### DESCRIPTION OF EQUIPMENT

A model branchpipe was first constructed as depicted in Fig.1. It was made from brass except for the foam-forming pipe sections which were of Perspex and allowed observation of the pattern of foam formation.

An upstream orifice 1.6 mm (0.06 in) dia was selected as the smallest practical size without introducing precision engineering problems or a high probability of random blockages by extraneous particles.

It is necessary to disperse the jet, and the method selected was to use two orifices with a turbulence chamber between, because this design is simple to construct. The two orifices were separated by spacing cylinders which permitted the length and diameter of the turbulence chamber to be varied. The provision of several orifice plates permitted the upstream and downstream orifices to be varied around the selected diameter of 1.6 mm.

The air induction chamber was 25.4 mm long x 25.4 mm dia (1 in x 1 in) and could not be varied in this first model. The foam-forming pipe could be assembled in a multiplicity of arrangements using various lengths of Perspex pipe of 4 diameters, connected by brass unions. Change in diameter was made using an appropriate brass reducing union. Each reducing union had 12.7 mm ( $\frac{1}{2}$  in) of parallel section at each end and the diameter change took place over the centre 12.7 mm length. For simplicity the numerous pipe configurations used are designated by stating the length of straight pipe section of each diameter used, and the 3 x 12.7 mm length of each reduction fitting must be added to obtain the total pipe length. Perforated plates or gauze discs could be inserted in the foam forming pipe at any of the brass unions between two pipe sections. The orifices were sharp edged and the reducing connections were straight, so that no contour machining was necessary in the construction.

The model branchpipe was mounted horizontally on the top of a 9 l (2 gal) container in which the foam liquid, diluted to the required concentration, was placed. Air was supplied to the container through a 12.7 mm dia flexible tube to force the foam liquid through the branchpipe. A plug on the liquid outlet enabled the discharge to be controlled. The air pressure could be varied at source up to a gauge pressure of 900 kPa (130 lb/in<sup>2</sup>). When arranged in this way the model branchpipe was 80 cm (31.5 in) from the ground, and the throw of the jet is related to this height.

Figure 30 shows the model branchpipe arranged in this manner.

Several other modifications to the model branchpipe were made and these are described at appropriate places later in the report.

When investigations with the Perspex model had progressed towards completion, an all-brass model was constructed to the preferred dimensions. Several adjustments were made after this model was tested resulting in the final preferred design which is shown in Fig 20.

#### MATERIALS USED

Potable water, 250-280 ppm total hardness, 170 ppm carbonates, was used to prepare the foam liquid solutions. The water temperature was 10-15°C, and the air temperature around 15°C.

The following foam liquids were used.

|            |   |  |
|------------|---|--|
| Protein A  | ) |  |
| Protein B1 | ) | Manufactured in U.K. and conforming to Defence Standard 42-3 |
| Protein B2 | ) |  |

Protein C - Manufactured in Europe

|                  |                                 |
|------------------|---------------------------------|
| Fluoroprotein A) |                                 |
| Fluoroprotein B) | From different UK manufacturers |

Synthetic - Product normally used for high expansion foam

Light water 194

#### EXPERIMENTAL PROCEDURE

Nine litres (2 gals) of solution were prepared in the container, the branchpipe was assembled on the outlet, and the container stood on level ground. The air supply to the container was adjusted to the required pressure and the plug cock was opened fully to permit foam discharge to commence. Discharge was allowed to proceed for at least 5 seconds before sampling to permit equilibrium to be established.

Samples were collected as follows

Shear stress - direct into the measuring pot at a distance of  
approx 1.5 m (5 ft) from the branchpipe outlet

Expansion - into a 1.25 l (0.3 gal) plastic beaker at a distance of  
approx 1.5 m from the branchpipe outlet

Drainage - direct into the drainage measuring pan at a distance of  
approx 1.5 m from the branchpipe outlet

Discharge rate - into a plastic 10 l (2.2 gal) container at  
approx 0.3 m (1 ft) from the branchpipe outlet

Shear stress measurements were made 1 minute after collecting the sample using the torsional vane viscometer described in Defence Standard 42-3.

Twenty-five % drainage times were from a pan 50 mm (2 in) deep, 187 mm

( $7\frac{3}{8}$  in) dia calculating the weight of foam from the pan volume of 1400 ml, and the expansion, which was determined separately. Timing was commenced from the drainage pan being half full.

The expansion was determined by weighing 1250 ml of foam in a plastic beaker.

Discharge rates were determined by collecting the total discharge in a tared plastic container for a period of 30 or 60 seconds, and weighing.

Throw distances were noted from markers on the floor at 0.3 m spacings. In many cases the jet dispersed to some extent and the mid-point of the dispersal pattern was estimated.

Because of the large extent of the investigation, on most tests only single observations were made, the object being to cover a large area of investigation in the most economic way. In tests of particular interest duplicate or triplicate determinations were made. Approximately 750 measurements were made. One 9 l mix of solution usually permitted tests of three pipe configurations, the expansion, shear stress, 25 per cent drainage time and throw being measured for each configuration. The three tests were usually completed in 30-45 minutes, depending on the drainage time. This limited changes occurring because of premix time but with some foam liquids appreciable changes will occur in less than 1 hour.

#### EXPERIMENTAL RESULTS AND DISCUSSION

It is not appropriate to record all the results, and a selection has been made to illustrate the principles which have been established. A problem that arose frequently was that a change would be made, to say the foam-forming pipe outlet, which gave improved results. It would then have to be decided to what extent previous ground must be re-covered to determine if this improvement was dependent upon other variables such as turbulence chamber dimensions, upstream and downstream orifice sizes, pressure, type of foam liquid, concentration, dimensions of other sections of the foam-forming pipe etc. The number of possible combinations of the variables in the system totals tens of thousands and the only practical approach was to endeavour to establish principles of branchpipe behaviour.

Unless otherwise stated, a pressure of 690 kPa ( $100 \text{ lb/in}^2$ ) was used.

#### INITIAL CHOICE OF TURBULENCE CHAMBER DIMENSIONS

The model branchpipe was assembled with no foam forming section so that the spray discharge pattern could be observed. The upstream orifice was chosen as 1.6 mm ( $1/16$  in) dia, and two sizes of downstream orifice were used and five pressures. The observations of the spray pattern with water are shown in Table 1.

Table 1

| Down-stream orifice dia mm | Turbulence chamber |           | Spray quality and gauge pressure |                                 |                                 |                                 |                                  |
|----------------------------|--------------------|-----------|----------------------------------|---------------------------------|---------------------------------|---------------------------------|----------------------------------|
|                            | Dia mm             | Length mm | 138 kPa (20lb/in <sup>2</sup> )  | 276 kPa (40lb/in <sup>2</sup> ) | 414 kPa (60lb/in <sup>2</sup> ) | 552 kPa (80lb/in <sup>2</sup> ) | 690 kPa (100lb/in <sup>2</sup> ) |
| 2.0                        | 19                 | 6.35      | 0                                | 0                               | 0                               | 0                               | 0                                |
| "                          | 19/12.7            | 6.35+ 9.5 | 0                                | 0                               | 1                               | 2                               | 3                                |
| "                          | 19/12.7            | 6.35+12.7 | 0                                | 0                               | 0                               | 1                               | 3                                |
| "                          | 19/12.7            | 6.35+22.2 | 0                                | 0                               | 3                               | 3                               | 3                                |
| "                          | 19                 | 15.9      | 0                                | 0                               | 0/1                             | 1                               | 1                                |
| "                          | 19                 | 19.0      | 0                                | 0                               | 0/1                             | 2                               | 2/3                              |
| "                          | 19                 | 28.5      | 0                                | 0                               | 0/1                             | 2/3                             | 2/3                              |
| 1.2                        | 19/12.7            | 6.35+22.2 | 0                                | 1                               | 2                               | 2/3                             | 2/3                              |

SPRAY CHARACTERISTICS OF WATER WITH VARIOUS TURBULENCE CHAMBER DIMENSIONS AND PRESSURES: AND 1.6 mm DIAM.UPSTREAM ORIFICE

0 = solid jet - no spray

1 = slight break-up: distinct solid centre

2 = considerable break-up

3 = good spray with no marked solid centre

From these observations an initial selection of orifice and turbulence chamber dimensions was made as follows, and designated Orifice Conditions A.

ORIFICE CONDITIONS A

UPSTREAM ORIFICE = 1.6 mm (0.06 in) dia

TURBULENCE CHAMBER = 6.35mm (0.2 in) length at 19 mm (0.75 in)dia  
+22.2mm (0.9 in) in) " " 12.7 mm (0.5 in)dia

DOWNSTREAM ORIFICE = 2.0 mm (0.08 in) dia

Figure 2 shows the discharge rate of water with orifice condition A.

Figure 2A shows data obtained later in the investigation using a larger upstream orifice and illustrates how the turbulence chamber length affects the discharge rate as well as the spray pattern.

TESTS WITH SIMPLE PIPE CONFIGURATION AND ORIFICE CONDITION A

Tests were first made using 2 per cent synthetic foam liquid and simple pipe configurations, of the type shown in Figs 3A and 3B, varying the length and diameters of the pipe sections.



With 45 cm (17.7 in) length of unrestricted pipe of 25.4 mm dia, or 12.7 mm dia; or with 15 cm (6 in) length 9.5 mm (0.37 in) dia, no foam was formed. With 15 cm or 30 cm (11.8 in) of 6.3 mm (0.24 in), pipe foam was produced. When the 45 cm length of 25.4 mm dia pipe was restricted at the outlet to 12.7 mm dia, foam formation occurred close to the outlet and foam with an expansion of 10.7 was obtained. Restricting the outlet to 9.5 mm dia increased the zone of foam formation and reduced the expansion to 9.5. Restricting the outlet to 6.3 mm dia caused the pipe to flood and the foam to back-up through the air inlet holes. Three tests with 30 cm of 25.4 mm dia pipe followed by different lengths of 9.5 mm dia pipe provide a further illustration of the effect of the degree of outlet restriction on the expansion

2 per cent synthetic liquid

|   |                 |
|---|-----------------|
| 30 cm x 25.4 mm dia + reducer to 9.5 mm dia | = 9.6 expansion |
| " + 15 cm x 9.5 mm dia                      | = 5.6 "         |
| " + 30 cm x 9.5 mm dia                      | = 3.8 "         |

9 Another effect which was revealed in this first series of tests was that when the 25.4 mm dia pipe was reduced at the outlet by a 12.7 mm dia reducer, a wavering jet which tended to break up resulted. A straight length of 15 cm of 12.7 mm dia pipe after the reducer gave a steady coherent rope of foam.

Increasing the liquid supply pressure of pipes with a simple configuration reduced at the outlet, had a similar effect on the expansion as increasing the degree of outlet restriction, for example

2 per cent synthetic liquid

|  |                 |
|--|-----------------|
| 45 cm x 25.4 mm dia + 30 cm x 12.7 mm dia pipe     |                 |
| Supply pressure - 414 kPa (60 lb/in <sup>2</sup> ) | = 9.5 expansion |
| " " - 552 kPa (80 lb/in <sup>2</sup> )             | = 8.2 "         |
| " " - 690 kPa (100 lb/in <sup>2</sup> )            | = 6.7 "         |

A number of tests were made with 1 to 3 wire gauze discs inserted in either 9.5 or 12.7 mm dia pipes. Two types of gauze were used with various positions of the discs, and various pipe lengths. The effect of the gauze discs was similar to increasing the pipe restriction - expansions were reduced. None of the tests with simple pipe configuration, with or without gauze discs, produced foam with good 25 per cent drainage times, around 1.5 min being the best obtained.

A number of tests were made with 4 per cent Protein B1, using a 45 cm x 25.4 mm dia tube, reduced at the outlet. A 9.5 mm reducer at the outlet barely produced foam, whereas the same configuration readily produced foam with synthetic liquid. An outlet restriction of 45 cm x 12.7 mm dia, or 15 cm x 9.5 mm dia, was

necessary to produce foam readily with the protein liquid and this reduced the expansion to 3.5 and 4.4 respectively.

#### SUMMARIZING

Foam can be produced in a 45 cm length of 25.4 mm dia pipe constricted at the outlet. No substantial foam production occurs in the 25.4 mm pipe section and foam formation takes place at the constricted outlet. The degree of constriction is important. A 9.5 mm dia reducer or a short length of 12.7 mm dia pipe is optimum. Less constricted results in very poor foam, increased constriction reduces expansion and causes flooding and backing-up.

Increasing the liquid supply pressure reduces expansion, presumably because it increases flow rate and therefore the effect of constriction.

Reducing the total tube length reduces foam quality.

A short reducer at the outlet gives a wavering dispersed jet while a straight length of pipe at the outlet gives a smooth rope of foam.

Insertion of gauze discs in the pipe is not a particularly promising method of producing good foams.

Different foam compounds can behave markedly differently in the same branchpipe.

None of the foams produced had good drainage values although good expansions were obtained.

#### TESTS WITH PIPES HAVING A VENTURI THROAT AT THE INLET END

The tests with pipes having simple configurations showed that if the restriction of the outlet pipe was increased to obtain more working of the foam in the tube, the back pressure produced suppressed the intake of air and caused the expansion to fall. It was thought that this effect might be alleviated by introducing a narrow throat at the inlet end between the air inlet ports and the main foam making section. Configurations as depicted in Fig.3C, 3D, 3E or 3F were therefore experimented with.

Immediately it was found that much improved operation was obtained, backing-up was almost completely eliminated and there was much more freedom to vary the pipe configuration after the venturi throat, and foam quality was improved. Good foam could be produced in a straight pipe without any outlet restriction, providing the pipe was of sufficient length.

(2 per cent synthetic liquid  
(Orifice conditions A - 6.3 mm dia x 12.7 mm long throat - expanded stepwise  
(Fig.3C)

Plus 15 cm x 6.3 mm dia = good foam

Plus 15 cm x 9.5 mm dia = spray

Plus 15 cm x 12.7 mm dia = spray



A wide outlet pipe after the 6.3 mm dia throat gave better foam than a narrower pipe

2 per cent synthetic liquid

Orifice Condition A

| Outlet pipe                              | Expansion | Shear stress<br>N/m <sup>2</sup> | 25 per cent<br>Drainage time<br>min |
|--|-----------|----------------------------------|-------------------------------------|
| 45 cm x 12.7 mm dia                      | 7.5       | 5.8                              | 3.0                                 |
| 45 cm x 19 mm dia                        | 9.5       | 8.3                              | 4.1                                 |
| 30 cm x 25.4 mm dia + 12.7 mm<br>reducer | 10.0      | 8.3                              | 3.9                                 |

In some tests using protein A and 25.4 mm dia pipe, after the venturi, the pipe would flood and the foam on the circumference of the pipe was static, foam formation taking place in a central core surrounded by static foam.

TESTS WITH BAFFLED PIPES

The problem of ensuring that the branchpipe would always immediately establish a stable fully flooded state of operation prompted the investigation of placing 'baffles' in the outlet pipe. This can loosely be described as ensuring flooding by mechanical means as opposed to hydrodynamically.

The investigations were made with 6.3 mm dia venturi throat, 1.27 cm long, followed by around 20 cm of 19 mm dia pipe, reduced at the outlet to 12.7 or 9 mm (0.35 in) dia. Synthetic and protein foam liquids were used.

One, two, or three 'baffles' were inserted in the 19 mm dia pipe at various positions. Numerous designs of 'baffles' were tried, such as plastic discs with various arrangements of holes, or discs of wire gauze of various mesh sizes. One variation was to introduce an offset into the 19 mm dia pipe using two 90° bends. This novel and unusual design functioned quite well but the foam properties were not notably good.

The preferred baffle arrangement consisted of two semi-circular discs spaced 5 cm (2 in) apart, 15 cm or 20 cm from the venturi outlet. The discs were fixed in opposite segments of the pipe. This configuration is depicted in Fig.3G. Better foams were obtained with the discs close to the outlet end of the pipe than when they were close to the venturi throat, and there was no significant difference in foam properties when the discs were rotated into different planes - their relative position in opposing segments being maintained. Semi-circular discs were better than discs of smaller or larger segment, and two discs were better than a single disc which caused some fluctuation in the issuing jet.

Figs 5, 6 and 7 show data obtained with the preferred baffle arrangement.

Fig 5 illustrates how two different foam liquids behave differently in the same branchpipe. It could be anticipated that the drainage times and shear stresses would differ for different foam liquids, but not that the expansions would also differ, since we might expect the expansion to be fixed by the

branchpipe dimensions. This point is discussed later in the report. The 25 per cent drainage time continuously increased, up to the highest pressure used 828 kPa (120 lb/in<sup>2</sup>), while the expansion and shear stress approached limiting values.

Fig 6 illustrates the effect of changing the back pressure by changing the outlet restriction. Changing from an outlet attachment 12.7 mm dia x 5 cm long to a short reduction 9.5 mm dia, 1.27 cm long, increased the throw, while the 25 per cent drainage time and expansion were appreciably reduced. This sensitive interaction between outlet restriction and foam properties creates one of the most important problems in designing a good branchpipe. The different foam liquids behave differently and careful judgement is necessary to select a degree of restriction which will produce foam with good properties from a broad range of foam liquids.

Fig 7 shows the effect of varying the supply pressure of protein liquid on the foam properties at three concentrations. Expansion approaches a constant value at 690 kPa (100 lb/in<sup>2</sup>) and the concentration has no marked effect on the expansion. Increasing the concentration increases the 25 per cent drainage time at all pressures. The manner in which the pressure affects the shear stress depends upon the concentration. This can be explained thus - at 4 per cent concentration there is insufficient surface active material to furnish bubble surface in excess of that generated at 690 kPa, and therefore further pressure increase creates no more surface and no increase in shear stress. With 6 or 8 per cent concentration this limitation does not apply and therefore the shear stress increases when the pressure is increased.

#### TESTS WITH NO TURBULENCE CHAMBER, WITH IMPINGING JETS, AND WITH INDUCED AIR DISPERSION

The foams produced in the baffled pipe as illustrated in Fig 5, 6, 7 represented a substantial advance towards the desired objective but were still significantly inferior in shear stress and drainage time to foams produced in the No.2, 227 l/min branchpipe. Further improvements in design were therefore sought.

The adoption of the turbulence chamber principle to disperse the jet has the disadvantage that energy is dissipated in a section of the pipe where foam is not being produced (If the pressure energy was dissipated in the turbulence chamber and appeared as heat a temperature rise of only 2°C would result). Other methods of jet dispersal were therefore explored.

The first method investigated was the elimination of the upstream orifice so that the jet issued at full supply pressure from the downstream orifice into the venturi throat 1.6 and 2.0 mm dia orifices were used. In both cases the jet did not consistently issue as a solid stream but would sometimes disperse into a narrow angled

spray, considerable variation in the degree of dispersion being apparent each time the discharge was started. 19 mm dia pipe was used and in some tests a plastic disc having three 6 mm (0.24 in) dia holes was inserted in the pipe 1.3 cm from the venturi outlet so that the jet impinged violently on the disc. It was found that, using the 2 mm dia orifice, foam could be produced with 45 cm of 19 mm dia tube reduced to 5 cm of 12.7 mm dia at the outlet. The foam, using synthetic liquid, had an expansion of 9.7 but a low 25 per cent drainage time of 1.25 min. Reducing the pipe length or the outlet restriction markedly reduced foam quality or completely prevented foam formation.

Using the 2 mm dia orifice a similar foam could be produced with 20 cm (7.9 in) length of outlet pipe and no outlet restriction.

The low drainage times were not encouraging and this line of investigation was not progressed further.

The second method investigated was to provide an air inlet hole, 1.6 mm dia, into the turbulence chamber. This was positioned close to the periphery in the downstream orifice plate. With the upstream orifice 1.6 mm dia and the downstream orifice 2.4 mm (0.09 in) dia and 1.27 cm between the orifice plates, air was induced into the turbulence chamber and the jet was dispersed into a dense central core surrounded by less dense spray. This arrangement appeared to achieve the objective of providing an increase in kinetic energy into the tube, because of the dense central core, but it was difficult to select a tube configuration which would lead to flooding and foam formation. With a 6.3 mm venturi throat, increased stepwise to 19 mm dia, 30 cm of 19 mm dia tube, reduced to 6.3 mm dia at the outlet a foam with expansion 8.85 and a 25 per cent drainage time of 3.0 min was obtained with 2 per cent synthetic solution. The throw was remarkably good at 3.5 m (11.3 ft) and the foam had a different appearance from most of the other foams produced, having a very smooth creamy texture. No tests were made with baffled tubes. Because of the difficulty of obtaining foam formation this idea was not pursued but appears to merit some further investigation.

The third method of obtaining maximum energy in the foam making section was to use an impinging jet spray. A 3.2 mm thick downstream orifice plate was made with 3 x 1.2 mm dia holes on 12.7 mm P.C.D. converging at an angle of  $20^{\circ}$  to the axis. This design does not have the same simplicity of accurate reproduction as the turbulence chamber jet. The discharge rate at 690 kPa (100 lb/in<sup>2</sup>) was 4.1 l/min, which was higher than with orifice conditions A which gave 3.2 l/min at 690 kPa. The impinging jets did not coalesce into a single uniform spray but changed at the impingement point to 3 partially intermingled cones of spray. The spray angle was wider than the turbulence chamber sprays.

The general behaviour of this impinging jet was similar to the turbulence chamber jets. The tube length had to be adequate, and the outlet restriction carefully selected. Operation was improved by the introduction of a venturi throat, but the best operation was obtained with a 9.5 mm throat as compared with 6.3 mm with the turbulence chamber jets. This was consistent with the higher discharge rate and wider spray angle. A substantial number of pipe configurations was tested and the foam properties did not show any significant improvement when compared with those obtained with turbulence chamber jets. Fig.8 shows some of the results obtained.

#### TESTS WITH A LARGER UPSTREAM ORIFICE

All the tests with the turbulence chamber jets had been made with orifice conditions A, which were selected by observing the shape of the spray when using water. Orifice conditions A employed a 1.6 mm dia upstream orifice and 2.0 mm dia downstream orifice. By increasing the upstream orifice diameter to be larger, instead of smaller, than the downstream orifice, the pressure drop in the turbulence chamber would be reduced and the issuing spray would have more kinetic energy. The discharge rate would also be increased.

This step was taken as follows:

|              |  |
|--------------|--|
| ORIFICE      | (Upstream orifice = 2.4 mm dia                   |
| CONDITIONS B | { turbulence chamber = .63 cm length x 19 mm dia |
|              | + 2.22 cm length x 12.7 mm dia                   |
|              | (downstream orifice = 2.0 mm dia                 |

Immediately this change was made, a very significant improvement in foam quality resulted.

Fig.9 compares foam properties using orifice conditions A and B and 2 per cent synthetic liquid. The expansion showed a significant increase while the 25 per cent drainage time was markedly increased, and the discharge rate had also increased.

Fig.10 shows the foam properties for protein B2, using orifice conditions B and the baffled tube. These foam properties compare well with those obtained in large branchpipes and it appeared that the baffled pipe with an inlet throat and orifice conditions B realised the primary objectives of the investigation. Seven different foam liquids were then tested in this model and the results are shown in Figs 11, 12 and 13, together with data for two 227 l/min branchpipes. The No 2 227 l/min branchpipe is that specified in Defence Standard 42-3 and is now rarely used in practice. The 5 X 227 l/min branchpipe is in widespread use in United Kingdom. These sets of data do not provide a rigid comparison because the same batches of foam liquid were not used in each of the branchpipes and the model:

the data for the 5X branchpipe is not complete and in several cases only figures for 6 per cent concentration were available - these are indicated on the figures.

Fig 11 shows that with most foam liquids the model produces foam with a lower expansion than No 2 and 5X branchpipes and this difference is most marked for the synthetic liquid and Light Water, which give the highest expansions. The very high expansion with synthetic liquid, shown for No 2 branchpipe, must be regarded with some reserve. It is suspected that some additional inclusion of air may have occurred when the jet struck the collecting bin and the high expansion value may not correctly represent the foam leaving the branchpipe.

Fig 12 and 13 show that the model produces foam with a shear stress and drainage time generally as good as the No 2 branchpipe and superior to the 5X branchpipe.

The model was also compared with the 2.0 U.S. gal/min laboratory branchpipe specified in U.S. Military Specification for Aqueous Film-Forming Foam Concentrate - MIL-F-24385. Four per cent protein B2 was used and 690 kPa (100 lb/in<sup>2</sup>).

|                               | U.S. | FRS  |
|-------------------------------|------|------|
| Expansion                     | 7.2  | 8.7  |
| Shear stress N/m <sup>2</sup> | 10.0 | 26.0 |
| 25 per cent drainage time-min | 1.7  | 6.3  |

Of particular interest is the performance of the model when protein C was used. The model produced foam with a lower expansion, a lower drainage time, and a very much lower shear stress than did the No 2 branchpipe. This poor performance of protein C in the model was investigated in some detail because its explanation promised to increase the understanding of branchpipe behaviour.

#### INVESTIGATIONS TO IMPROVE THE MODEL BRANCHPIPE PERFORMANCE WHEN PROTEIN C IS USED

The effect of liquid supply pressure and of concentration of protein C were first assessed and the results are shown in Fig 14 and 15. Note that in these tests the 12.7 mm dia outlet was 15 cm long, as compared with 5 cm used previously.

Fig 14 shows that increasing the liquid supply pressure causes a fall in expansion but a useful increase in the shear stress and 25 per cent drainage time. Fig 15 shows that increasing the concentration is a more effective method of improving the foam properties and that when the concentration is doubled to 8 per cent the expansion and shear stress equal that from No 2 branchpipe and the drainage time is greater. Protein C is a much more difficult liquid to foam than any of the other foam liquids used and does not so readily give a good expansion and drainage value. This is true both for the large branchpipes and the model. When however we consider shear stress, the model is markedly inferior to the two large branchpipes unless a concentration above 4 per cent is used in the model. It was thought that



increasing the back pressure, by a greater restriction of the outlet of the model, might absorb more energy in foam production and improve the foam properties. Fig.16 shows the foam properties with four different outlet restrictions. It can be seen that increasing the 12.7 mm dia outlet from 5 cm to 10 cm (4 in) resulted in a marked improvement of foam properties of protein C foam. It was then necessary to assess this change using the other foam liquids. This was done and the results are shown in Figs 17,18,19.

It can readily be seen that increasing the outlet restriction improves all the properties of protein C foam but that the other six foams all show a deterioration of properties.

It was thought that the improvement in protein C foam properties might be obtained, without deteriorating the other foams, by increasing the venturi throat length and reducing the outlet restriction to compensate the back pressure increase. This was done by increasing the venturi throat length from 1.27 cm to 6.3 cm, and reducing the 12.7 mm dia outlet pipe by 5 cm - leaving only the 12.7mm dia reducer at the outlet. All 7 foams were retested and the results were almost identical to those shown in Fig 17, 18 and 19. The expansion, shear stress and 25 per cent drainage time were all changed by the same amounts as those obtained with increase in outlet restriction from 5 cm to 10 cm of 12.7 mm pipe.

These tests illustrated well the difficulty, and perhaps the impossibility, of designing a branchpipe which will have optimum performance with all foam liquids.

As a result of the data in Fig 17-19 it was decided to retain the 5 cm outlet pipe on the model and accept the inferior performance with protein C.

#### EXPERIMENTS TO ARRIVE AT A FINAL PREFERRED DESIGN

A new model was constructed using brass throughout. The air induction section was reduced from 25.4 to 19 mm dia to streamline the design and the reduction into the venturi throat was made more gradual. The final design is depicted in Fig.20.

This all brass model was first tested using two sizes of downstream orifice, and 4 per cent of protein B2, at various liquid supply pressures. The results are shown in Fig.21 and are very interesting because of the opposing slopes of the two sets of curves. We have observed this phenomenon with large branchpipes, some of which give better foam when operated at lower pressures.

Sufficient studies have not been made to explain the changes between the two sets of curves in Fig.21. The change in downstream orifice size results in change in flow rate, which will affect the back pressure in the fixed pipe configuration: the spray character will change because of the change in flow-rate and the change in ratio between upstream and downstream orifice sizes. All these changes may be of different magnitude with different foam liquids. In some groups of tests, expansion

curves with opposing slopes were obtained, by changing the outlet restriction.

The all brass model was then tested with various upstream and downstream orifice sizes using 4 per cent protein B2 at 690 kPa (100 lb/in<sup>2</sup>). The results are shown in Figs 22 and 23. From these results a final choice was made of 2.2 mm dia downstream and 3.0 mm dia upstream orifice diameters

It is impossible to give a succinct interpretation of these important curves in Fig 22 and 23 but the following generalization may assist in consideration of similar problems with other branchpipes.

- 1) The total flow rate is one of the most important factors affecting foam properties
- 2) Excellent foams are produced in this model branchpipe when the flow rate is 5 l/min.
- 3) If the total flow is reduced to around 4 l/min (0.88 gal/min) by restricting either upstream or downstream orifice the shear stress and 25 per cent drainage time fall markedly but the expansion is not greatly changed.
- 4) If the total flow rises to 6 l/min (1.3 gal/min) expansion and drainage time fall slightly but shear stress is not greatly affected
- 5) If the total flow rises to 7 l/min (1.5 gal/min) expansion and drainage time fall markedly and shear stress also falls.

The final preferred design was then tested with protein B2 at various pressures and concentrations and the results are shown in Figs 24-27, while Table 2 gives foam properties for the seven foam liquids when tested at 690 kPa (100 lb/in<sup>2</sup>) and the concentration at which they are normally used.

#### CONSTRUCTION AND USE OF THE FINAL PREFERRED DESIGN

The essential details of the final design are shown in Fig.20 but for the convenience of those who may wish to construct and use this model branchpipe a detailed engineering drawing, and a recommended standard procedure for operation, are being assembled in a separate report.

Table 2

Foam properties of seven foam liquids when tested  
in the final design branchpipe at  
690 kPa (100 lb/in<sup>2</sup>)

| Compound           | Expansion | Shear stress<br>N/m <sup>2</sup> | 25% Drainage   |
|--------------------|-----------|----------------------------------|----------------|
| 4% Protein B2      | 8.4       | 23.4                             | 6mins 29secs   |
| 4% Protein A       | 7.1       | 37.1                             | 5mins 12secs   |
| 2% Synthetic       | 9.4       | 8.3                              | 5mins 15.4secs |
| 6% L.W.194         | 9.3       | 3.8                              | 3mins 27secs   |
| 4% Fluoroprotein A | 7.7       | 37.1                             | 5mins 4.3secs  |
| 4% Fluoroprotein B | 8.6       | 8.3                              | 3mins 53.1secs |
| 4% Protein C       | 6         | 35.8                             | 3mins 40secs   |

A comprehensive comparison of the model branchpipe with No.2 branchpipe using 9 different batches of protein foam liquid was provided from an associated laboratory. Triplicate tests were made with each branchpipe on each of the nine protein foam liquids at 4 per cent concentration. The overall average results are shown in Table 2A.

#### CRITERIA OF GOOD FOAM PROPERTIES

Throughout the report references have been made to 'good' foam properties and other similar adjectives are used. Some consideration of the criteria on which such assessments have been made is appropriate.

The foam properties which are most effective for fire control and extinction are not simply defined. According to circumstances various effects will be of different relative importance, such as rapidity of control, rapidity of extinction, economical use of foam liquid or of water or of equipment, resistance to burnback, length of throw, etc. These effects depend upon amongst other things, the physical properties of the foam which can be changed by the branchpipe design, ie expansion, shear stress, drainage rate and velocity. The relationships are very complex and in some cases are in opposition; for instance a low shear stress will favour rapid control, while a high shear stress will favour resistance to burnback.

In this report the assessment of a good foam has not been based upon its suitability for a particular fire-fighting application, but upon the effectiveness of the mechanical operation of changing a liquid into a foam - ie how much air is

Table 2A

Comparison of Final Model with No 2 (227 l/min) Branchpipe 4 per cent protein, 690 kPa (100 lb/in<sup>2</sup>) - means of two tests

| Batch No | NO.2 BRANCHPIPE |                   |           |                           |                                | MODEL BRANCHPIPE |                   |           |                           |                                |
|----------|-----------------|-------------------|-----------|---------------------------|--------------------------------|------------------|-------------------|-----------|---------------------------|--------------------------------|
|          | Air temp<br>°C  | Premix temp<br>°C | Expansion | Shear<br>N/m <sup>2</sup> | 25%<br>Drainage<br>Time<br>min | Air Temp<br>°C   | Premix temp<br>°C | Expansion | Shear<br>N/m <sup>2</sup> | 25%<br>Drainage<br>Time<br>min |
| 369      | 18.9            | 16.7              | 11.4      | 25.2                      | 6.2                            | 19.6             | 18.3              | 8.85      | 32.8                      | 8.65                           |
| 380      | 20.0            | 17.2              | 9.25      | 21.8                      | 4.0                            | 18.9             | 18.3              | 8.7       | 26.5                      | 6.6                            |
| 156      | 16.7            | 16.7              | 10.55     | 21.2                      | 4.55                           | 15.6             | 15.0              | 8.67      | 26.1                      | 6.75                           |
| 421      | 13.3            | 15.0              | 10.62     | 21.4                      | 5.65                           | 12.4             | 15.0              | 8.65      | 29.2                      | 7.5                            |
| 455      | 13.3            | 15.0              | 10.8      | 23.3                      | 5.6                            | 14.5             | 15.0              | 8.65      | 30.1                      | 7.5                            |
| 461      | 13.3            | 13.9              | 10.5      | 23.5                      | 5.65                           | 13.3             | 15.0              | 8.67      | 29.3                      | 7.65                           |
| 466      | 13.3            | 15.0              | 10.65     | 22.8                      | 5.9                            | 14.5             | 15.0              | 8.65      | 29.7                      | 8.1                            |
| 472      | 14.5            | 13.9              | 10.37     | 21.9                      | 5.3                            | 14.5             | 13.3              | 8.62      | 29.4                      | 7.8                            |
| 490      | 14.5            | 13.9              | 10.42     | 20.4                      | 5.7                            | 14.5             | 13.3              | 8.7       | 28.4                      | 7.8                            |
| Average  | 15.3            | 15.25             | 10.51     | 22.4                      | 5.39                           | 15.3             | 15.35             | 8.7       | 29.1                      | 7.59                           |

incorporated and how effectively are the air and water dispersed. Shear stress and drainage rate are indirect measures of the degree of dispersion, although this also depends upon the expansion and the foam liquid constituents. If by this approach the most efficient branchpipe design is obtained, and this produces foam which is too stiff for a particular application it will probable be possible to profit from the efficient branchpipe design by using a lower concentration of foam liquid.

#### THE EXPANSION FROM A BRANCHPIPE

Once a reasonably good branchpipe design is obtained the foam leaves the pipe as a coherent rope of foam and there appears to be no substantial loss of air from the foam. It is surprising therefore to find that with a fixed pipe configuration substantially different expansions are obtained with different foam liquids and the inclusion of air is not simply dependent upon the mechanical details of the branchpipe construction.

Another puzzling observation is that in the many pipe configurations tested, only in a few instances, were expansions slightly above 10 obtained. Why cannot expansions of 20 or 30 be obtained. Expansions of this order are easily produced

by the foam liquids used when a laboratory foam generator is used, or in a medium expansion branchpipe which has a different design principle.

One useful calculation is to compare the area of the downstream liquid orifice with the area of the narrowest section of the branchpipe. Assume the induced air is accelerated to the velocity of the liquid in the narrowest section of the branchpipe, then the expansion will be the ratio of the narrowest section to area of the liquid orifice. This can be referred to as the simple theoretical expansion. It does not allow for any variation in liquid velocity in the cross section of the liquid orifice, any increase of liquid velocity due to contraction after leaving the orifice, kinetic energy imparted to the induced air, deceleration due to pipe friction and turbulence, compression of the induced air above atmospheric pressure, nor energy required for surface creation.

In the final design which is shown in Fig 20

$$\text{Simple theoretical expansion } \frac{(6.25)^2}{(2.2)^2} = 8.32$$

The expansions shown in Fig 17, for the various foam liquids, compare with this theoretical expansion as follows

| <u>Foam liquid</u> | <u>Model Branchpipe Expansion</u><br><u>Percent of theoretical expansion</u> |
|--------------------|--|
| Protein B2         | 92 per cent  |
| Protein A          | 91 per cent  |
| Synthetic          | 108 per cent   |
| Light Water        | 109 per cent   |
| Fluoroprotein A    | 96 per cent  |
| Fluoroprotein B    | 98 per cent  |
| Protein C          | 57 per cent  |

Since the energy losses enumerated above must apply to some extent, these high percentage expansions indicate that the compression of the induced air must be a significant factor in determining expansion. This compression must occur in the converging approach section to the venturi throat and therefore attention to the design of this converging section is indicated for future study.

The data in Fig 21 is for a throat diameter of 6.3 mm with two sizes of orifice which gives two different theoretical expansions. Four per cent protein B was used and various supply pressures as follows:

|                        |                    | 2 mm Orifice-theoretical<br>expansion=10.1 |                               | 2.2 mm orifice theoretical<br>expansion=8.32 |                               |
|------------------------|--------------------|--|-------------------------------|--|-------------------------------|
| Liquid supply pressure |                    | Observed<br>Expansion                      | Per cent<br>of<br>theoretical | Observed<br>Expansion                        | Per cent<br>of<br>theoretical |
| kPa                    | lb/in <sup>2</sup> |  |                               |  |                               |
| 552                    | 80                 | 8.9  | 88                            | 7.8  | 95                            |
| 690                    | 100                | 7.8  | 77                            | 8.3  | 100                           |
| 828                    | 120                | 7.1  | 70                            | 8.4  | 101                           |

At 552 kPa the best expansion is obtained with the arrangement with the higher theoretical expansion operating at a lower efficiency, while at 828 kPa the best expansion was obtained with the lower theoretical expansion operating at a higher mechanical efficiency.

The data in Fig 8 is for the tests with impinging jets. In these tests the best operation was obtained with a 9.5 mm dia throat. The theoretical expansion was 21, but the highest expansion obtained was only 44 per cent of this = 9.2

In these investigations only throat diameters of 6.3 and 9.5 mm were used - this is a twofold difference in cross sectional area. It may be rewarding to experiment with throat areas varying by 10 per cent steps to discover if a clearly defined optimum throat area exists.

There seems no reason why the converging venturi section should not be omitted. In this case the expansion will be limited to the simple theoretical expansion, since no compression can occur without an equivalent velocity fall as there is no change in cross sectional area, but the diameter of the throat could be increased slightly to off-set this. The length of the throat and spray angle will require appropriate matching. This would lead to a simple engineering construction and merits examination when larger branchpipes are constructed.

#### THE EFFECT OF FOAM LIQUID PROPERTIES ON EXPANSION

As stated above, there appears to be no loss of air from the foam rope as it leaves the branchpipe and therefore differences in expansion must originate in differences in the amount of air induced by the spray. This was verified by constructing a small brass branchpipe with a connection on the air induction section which could be connected to a water manometer and would indicate the negative pressure at the air induction point when the branchpipe was operating. This model was a short, unbaffled, branchpipe which did not produce foam to give variable back-pressures. Measurements were made using a selection of 10 foam liquids and with water. The results are shown in Fig 28, plotted against the

surface tensions of the liquids. They show very definitely that at any one pressure, with a fixed branchpipe configuration, the negative pressure created varies between different foam liquids, and therefore the quantity of air induced will vary, and we will obtain foams with different expansions. Fig 28 also indicates that the surface tension correlates with the suction created, the lower surface tensions favouring higher suctions; perhaps because the jet disperses more effectively. As the pressure increases the effect of differences in surface tension diminishes. If we examine the linear sections of the curves in Fig 28 we obtain:

| Liquid supply pressure |                    | Suction pressure at 30 mN/m as percentage of suction pressure with water |
|------------------------|--------------------|--|
| kPa                    | lb/in <sup>2</sup> |  |
| 552                    | 80                 | 125  |
| 690                    | 100                | 112  |
| 828                    | 120                | 101  |

In this branchpipe therefore the effect of surface tension on the suction was reduced to a negligible value at 828 kPa (120 lb/in<sup>2</sup>) except for liquids with surface tensions below 30 mN/m - ie the two fluorochemicals used in these tests, and in those cases the reduction is substantial. This suggests that a useful experimental technique to discover good jet designs is to measure the suction created with two liquids of different surface tensions. It may be possible to design a jet and venturi combination in which the quantity of air induced, and therefore the foam expansion is independent of the pressure at lower pressures than 828 kPa. The correlation between suction and surface tension in Fig 28 is not perfect. We would expect a better correlation if the dynamic surface tension was used in place of the static surface tension, but these values were not determined.

The data in Fig 5 & 8 each give the expansions obtained with two foam liquids of different surface tensions, at various pressures, and with a fixed pipe configuration. Fig 5 is for protein A and synthetic liquid, and Fig 6 for protein B1 and synthetic liquid. In both cases the differences in expansion between the two foams increased with increasing liquid supply pressure and did not decrease as we would expect from the above deductions from the surface tension data. Presumably changes in back pressure resulting from changes of

flow rate with pressure, disguise the surface tension effect.

In Fig 29 the data for the different foams produced in the 19 mm (0.75 in) dia baffled branchpipe, taken from Figs 11,12 and 13, are plotted against the surface tensions. Protein C is omitted because of its anomalous behaviour. Fig 29 shows that the model branchpipe expansion has a fair correlation with the surface tension of the foam liquid used, the lower surface tensions giving higher expansions, as expected from the suction measurements. Higher expansions will favour higher shear stresses and longer 25 per cent drainage times, while lower surface tensions will favour lower shear stresses and shorter drainage times. The net result of these opposing effects is of interest: low shear stresses are preferred because they give more rapid fire control, while long drainage times are preferred because they indicate good foam stability. Fig 29 shows that the net result is that low surface tension liquids give foams with greatly reduced shear stresses and these will give rapid fire control, while the 25 per cent drainage times fall but not disastrously. Other properties of the foams such as breakdown on contact with hot fuel have also to be taken into account.

#### CHOOSING THE DEGREE OF OUTLET RESTRICTION

The data in Fig 6 show that, with baffled tube that is operating fully flooded, increasing the outlet restriction reduces expansion, shear stress, and 25 per cent drainage time. This is the important relationship pertaining in most circumstances. Figs 17, 18 and 19 show that it is applicable to most foam liquids. Increasing the outlet restriction increases the throw, and this is desirable if the branchpipe is to be used on experimental fires. The throw varies approximately over the range 1 m(3.25ft) to 3.5 m as the outlet varies from 19 mm to 6.3 mm diameter.

The length of the outlet restriction affects the jet configuration, less than 5 cm length gives a wavering jet which breaks erratically, over 10 cm length gives a smooth coherent rope of foam.

The principle therefore is to select the minimum restriction which will provide the required throw and acceptable stability of the foam jet.

Two exceptions to this general principle were found. In wide pipes (25 mm dia) with no baffles, and just sufficient restriction at the outlet to cause foam formation at the outlet, a foam with high expansion (CA.12) large bubble size, and low shear is formed. A slight reduction in restriction in this case will cause a fall in expansion and an increase in shear stress and drainage time - the pipe operation changes from foam just forming at the outlet to a partially or fully flooded state of operation. Further increase in the outlet restriction



results in a fall in shear stress and drainage time as well as expansion.

The second exception is with liquids that do not foam readily, such as protein C. With such liquids, even in the baffled pipe, full flooding may not occur without some degree of outlet restriction and some of the induced air is not incorporated into the foam and is lost at the pipe outlet. In this case therefore an increase of expansion, drainage time, and shear stress, occurs up to a certain degree of restriction which ensures full foam formation. Further increase in outlet restriction then results in a fall of all properties.

These two exceptions to the general rule will probably not be of practical importance, although it will be useful to recognise when an unsatisfactory foam liquid such as protein C is encountered. As shown in Fig 15, such cases are best met by increasing the concentration.

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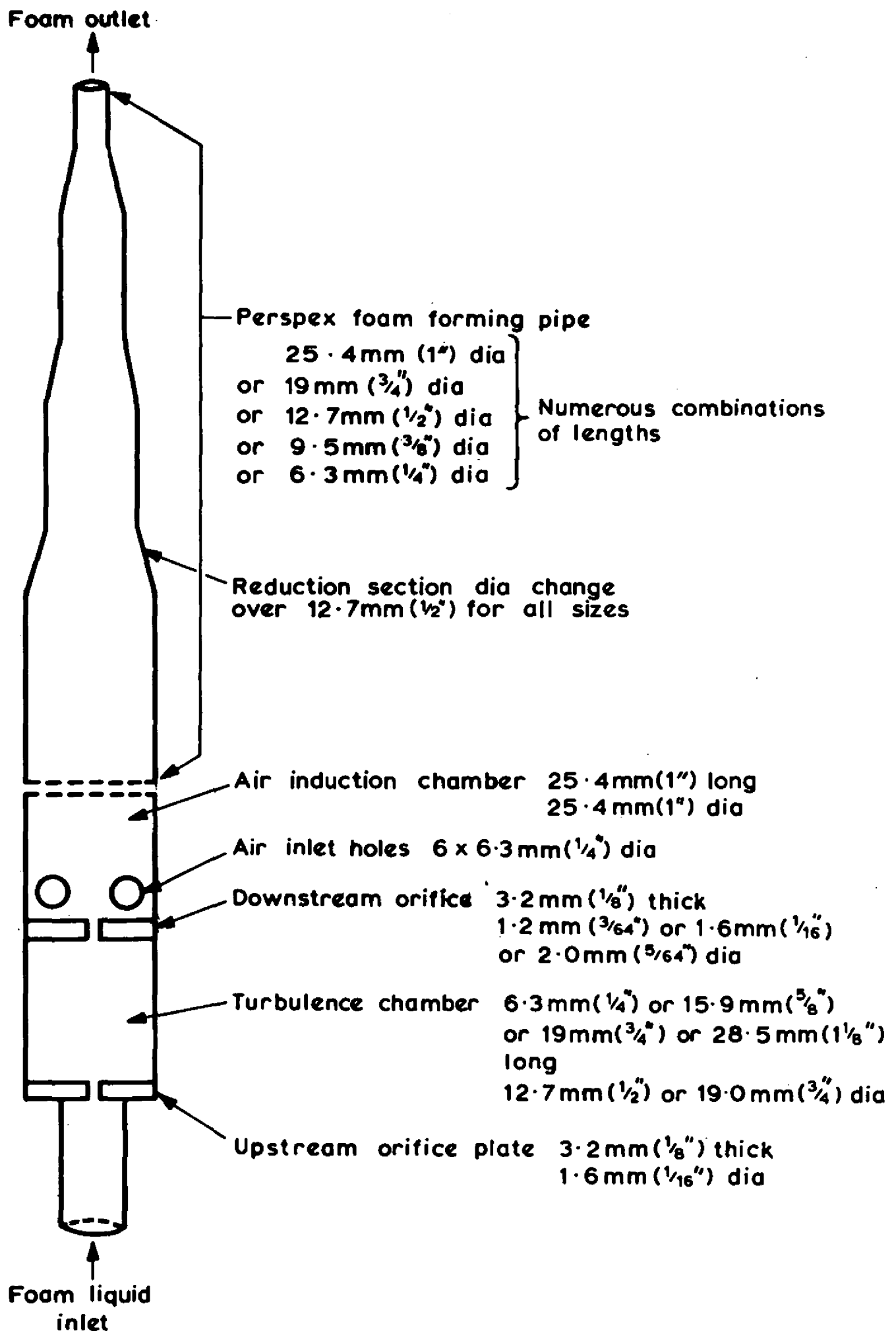


Figure 1 Model branchpipe with perspex foam pipe

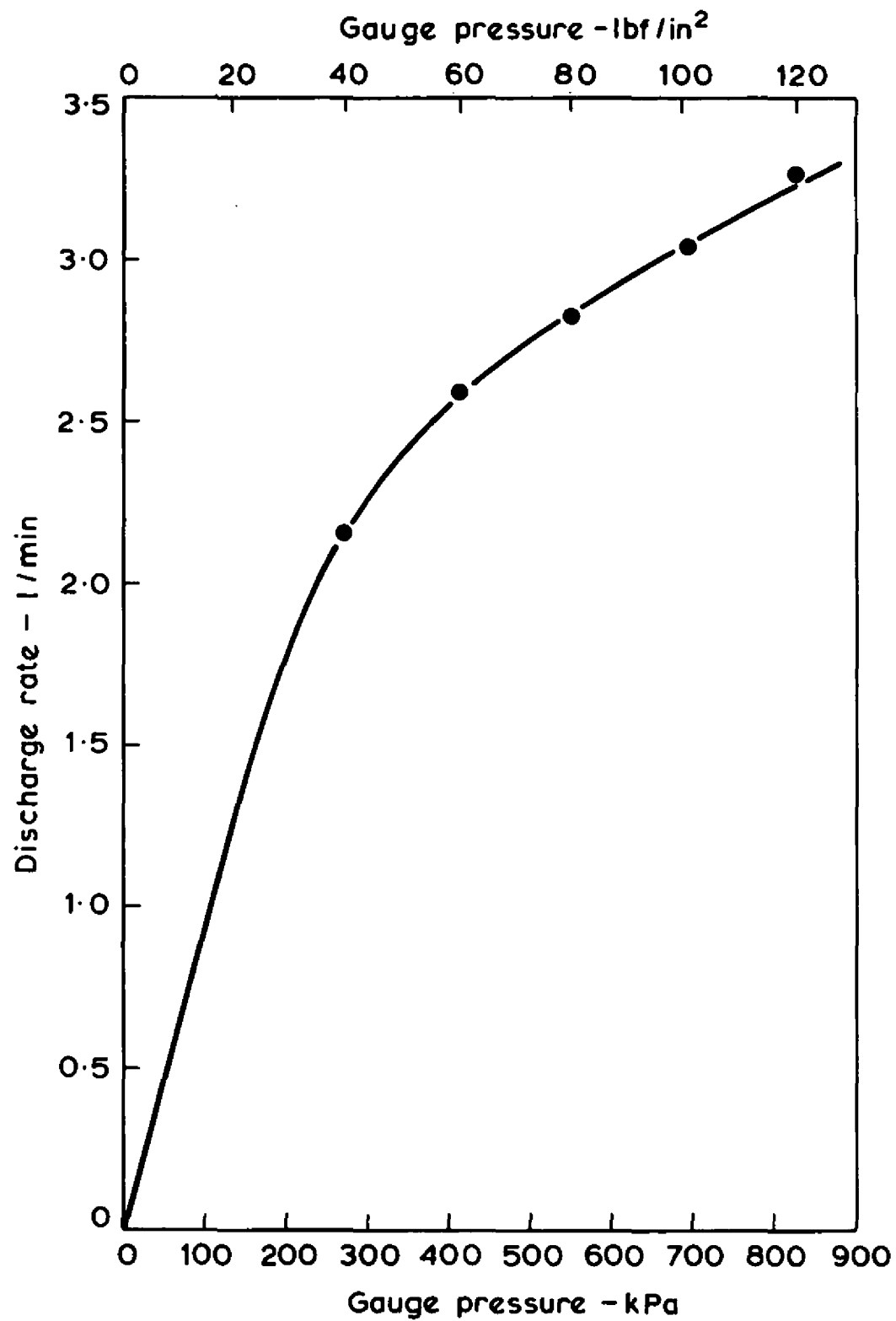


Figure 2. Discharge rate with orifice conditions A

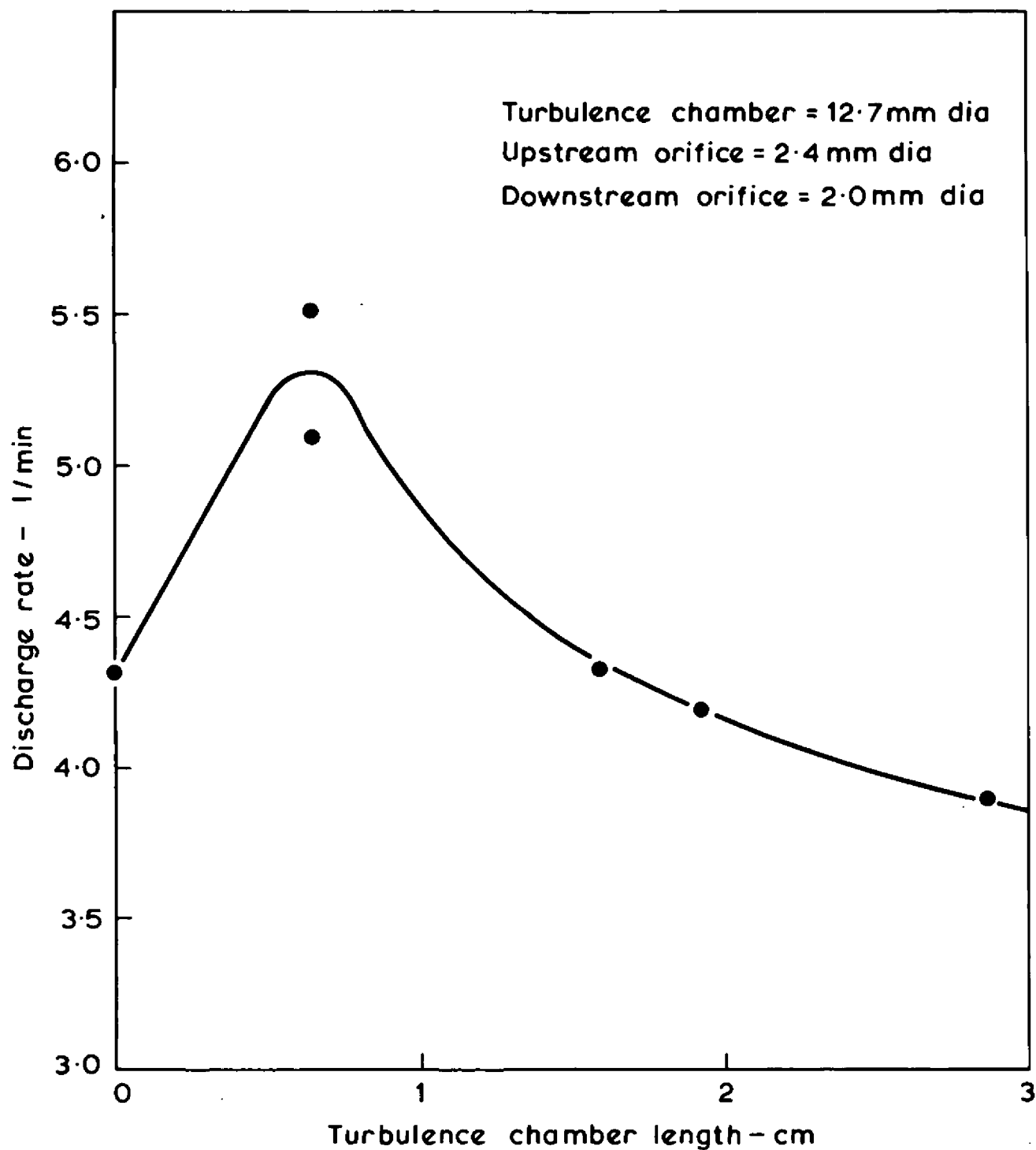


Figure 2A The effect of turbulence chamber length on discharge rate of water at 690 kPa (100 lbf/in<sup>2</sup>)



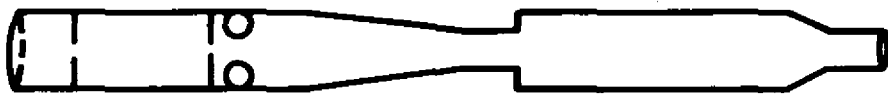
A. Simple / restricted



B. Simple / restricted



C. Short converging / throat / long diverging / restricted



D. Long converging / throat / increased / restricted



E. Long converging / throat / long diverging / restricted

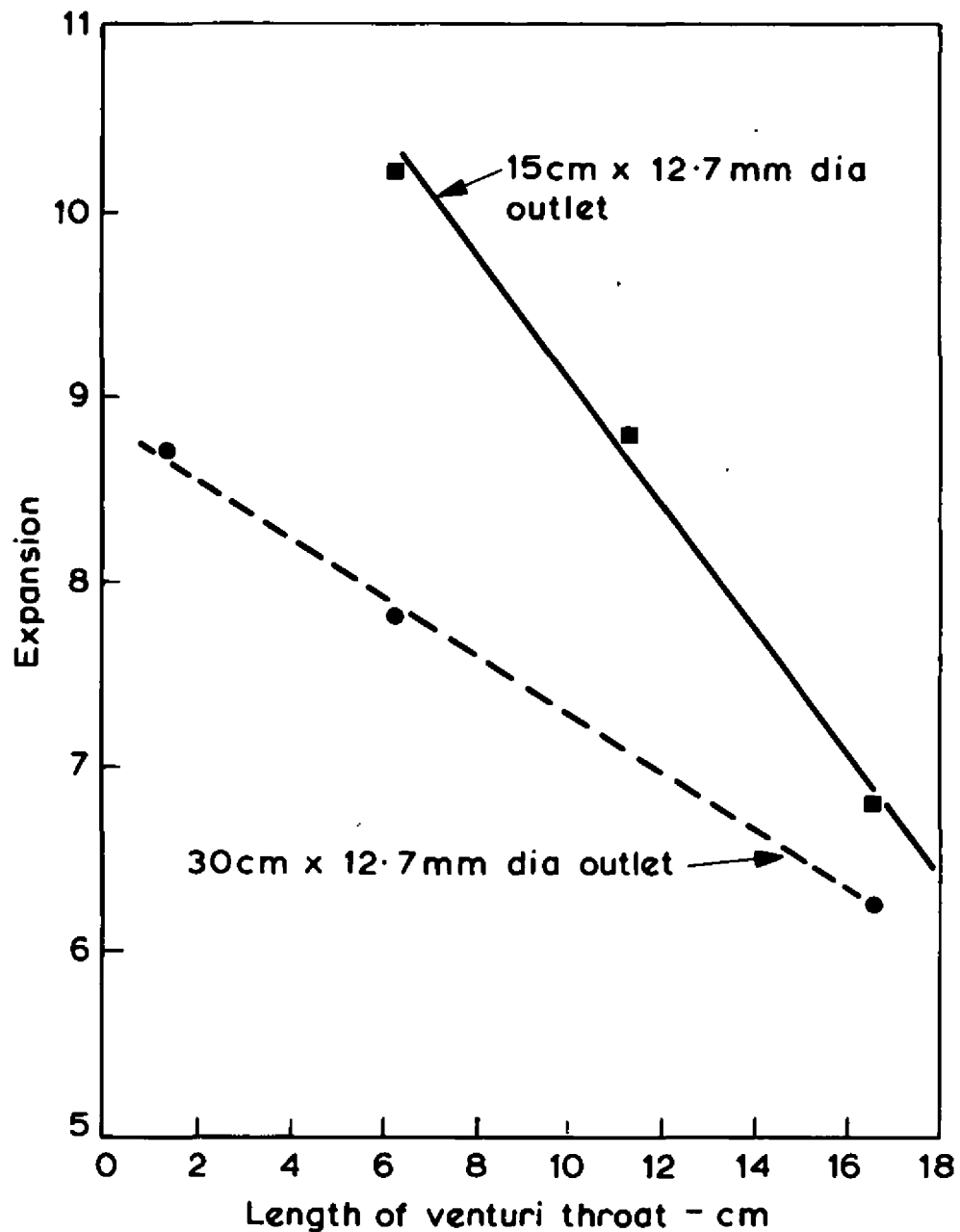


F. Short converging / throat / increased / restricted



G. Short converging / throat / increased / baffled / restricted

Figure 3 Various configurations of perspex model branchpipe



Orifice conditions A

2 per cent synthetic liquid

Venturi inlet 25.4 mm → 6.3 mm dia over 1.27 cm length

Throat dia = 6.3 mm

■ — — — ■ 12.7 mm dia outlet pipe 15 cm long

● - - - - ● 12.7 mm dia outlet pipe 30 cm long

Figure 4 The effect of venturi throat length on expansion

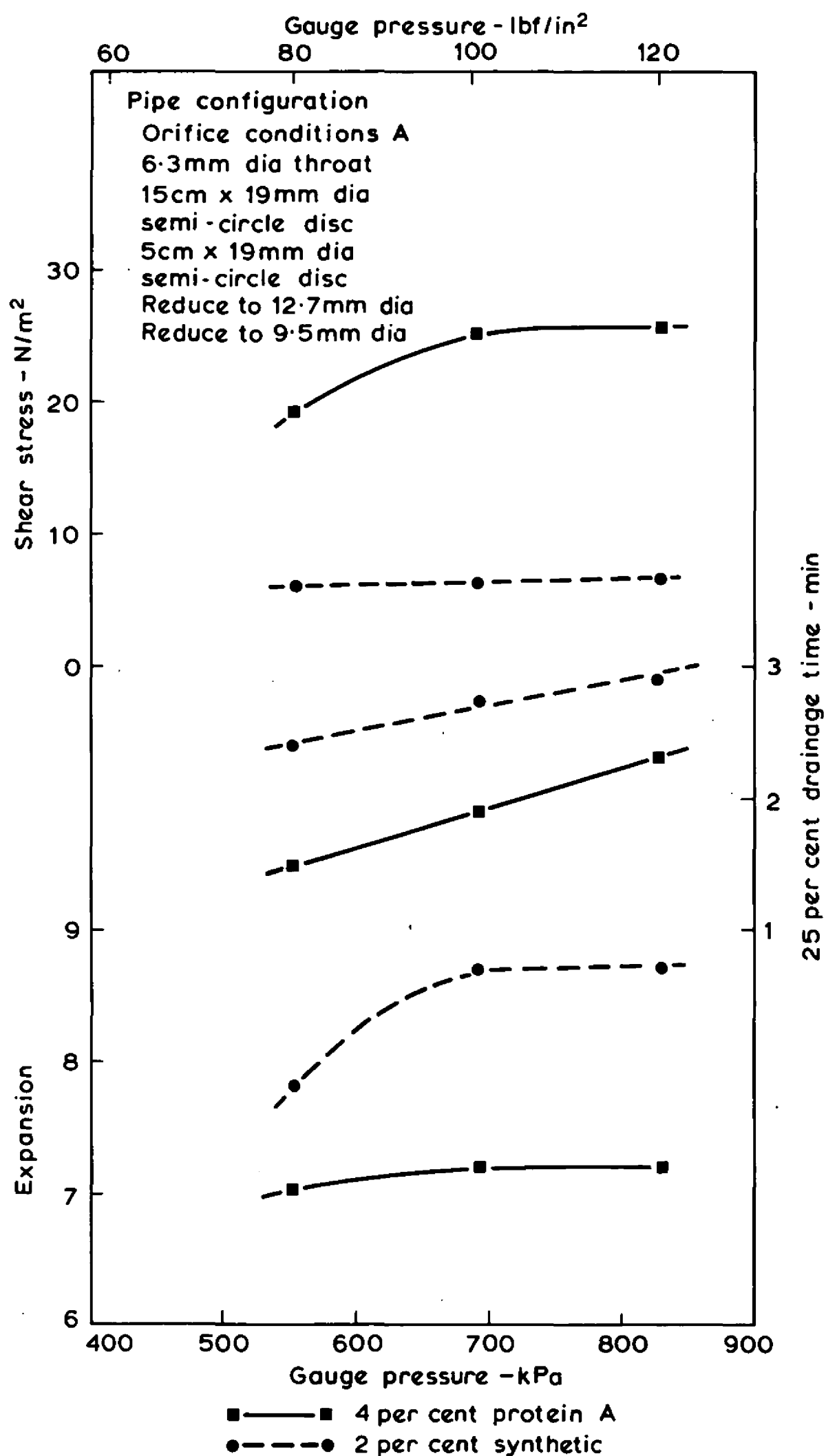


Figure 5 Foam properties from 19mm dia baffled pipe

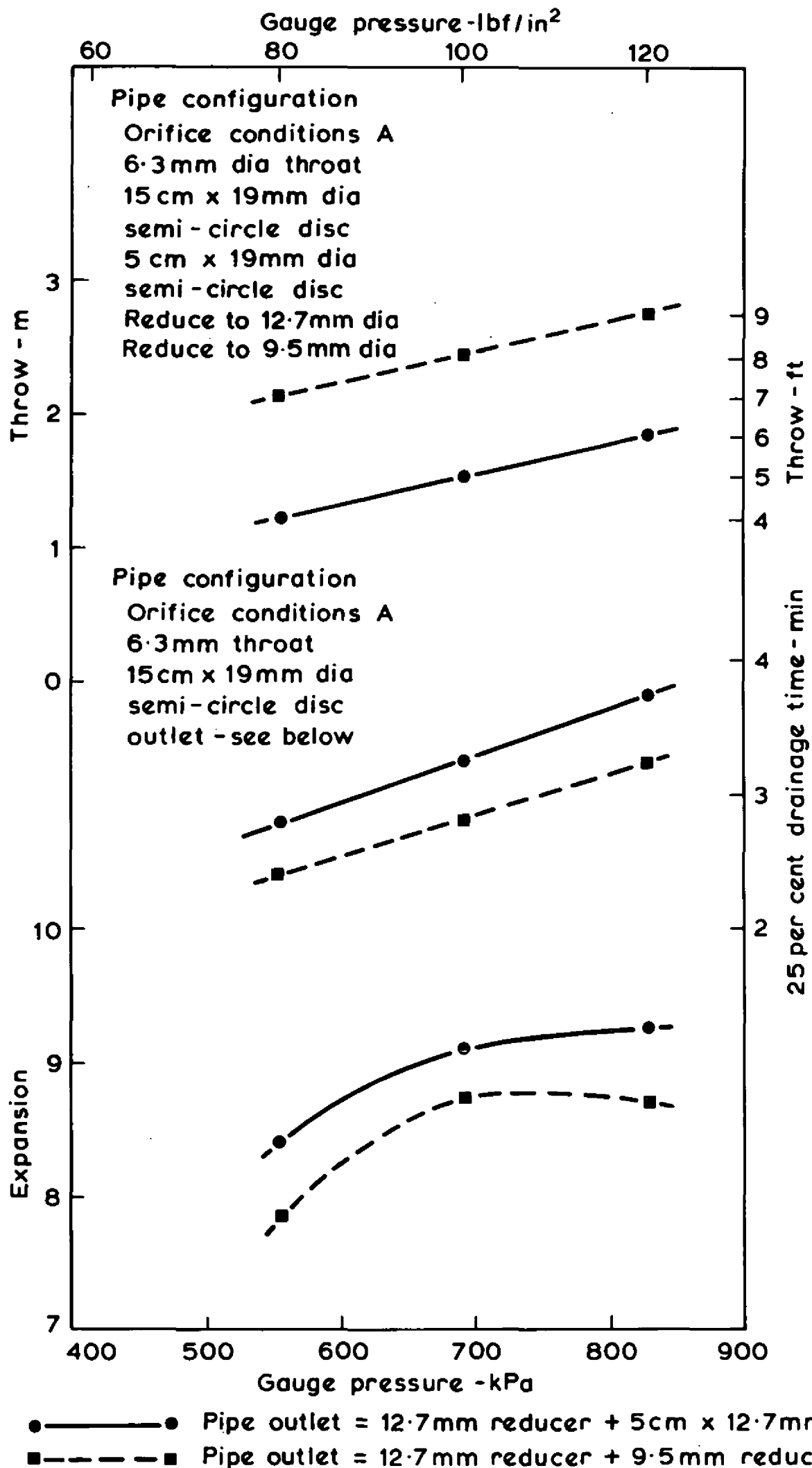


Figure 6 Foam properties from 19mm dia baffled pipe with 2 per cent synthetic



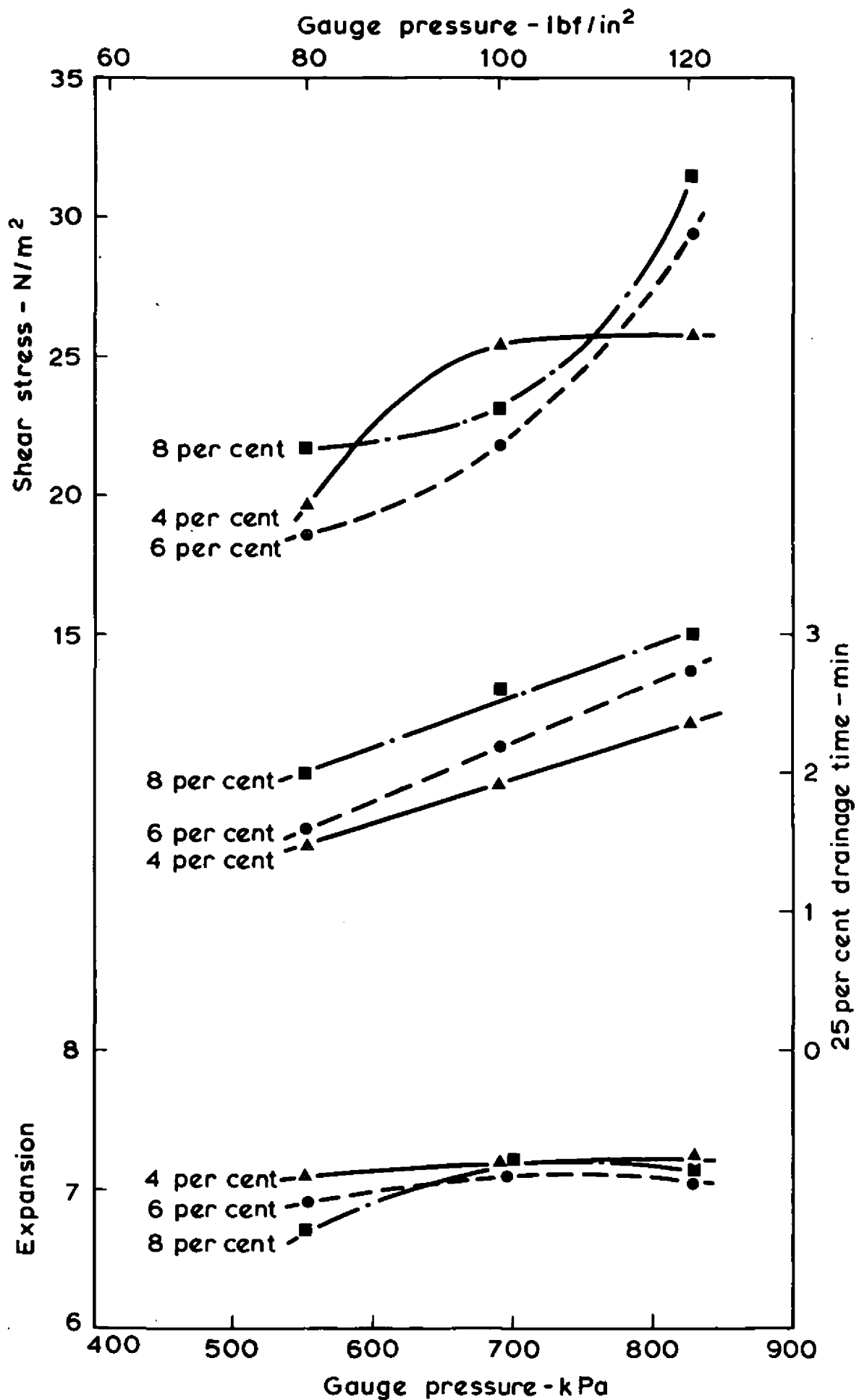


Figure 7 Foam properties from 19mm dia baffled pipe with various concentrations of protein A

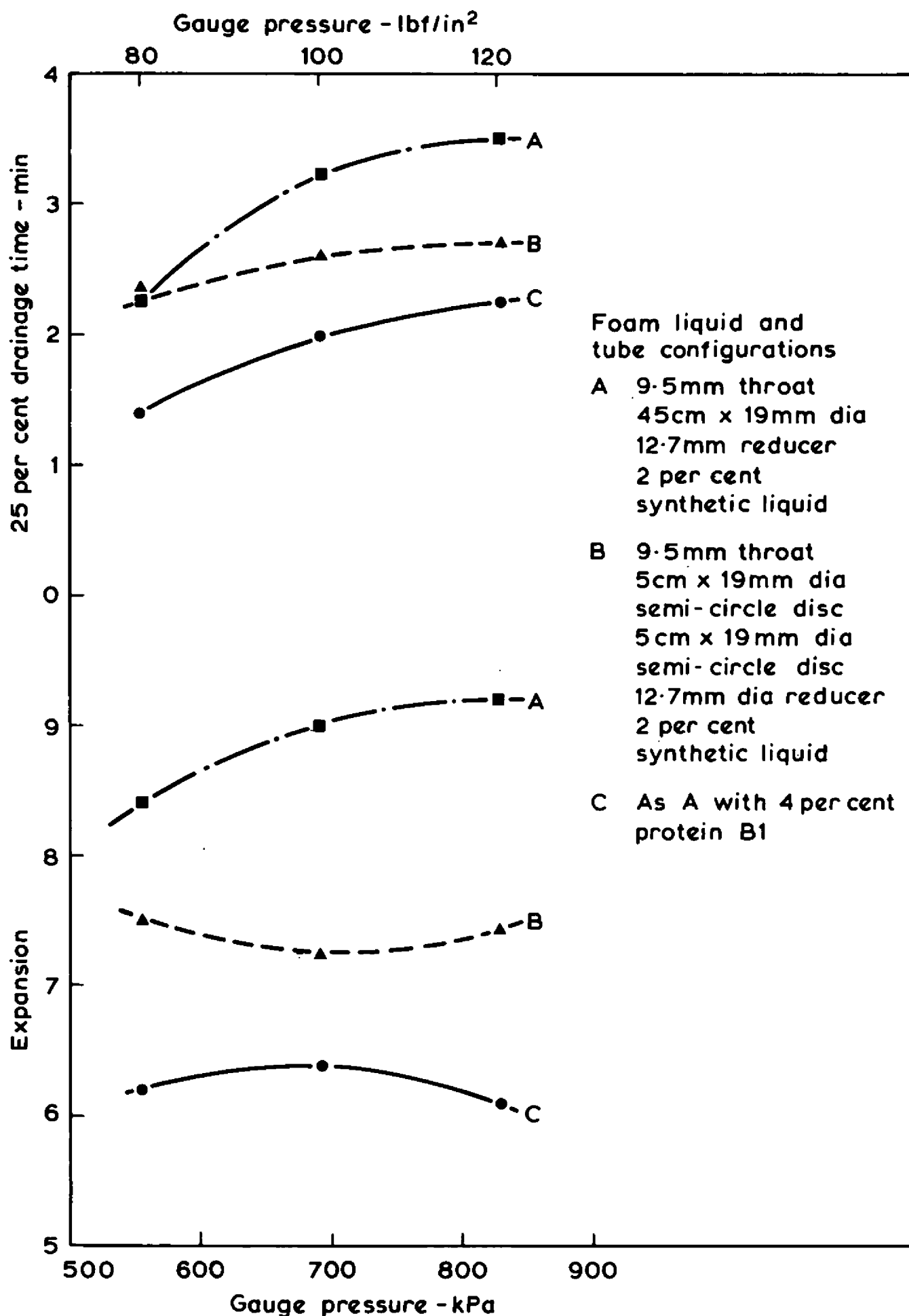


Figure 8 Foam properties using impinging jet

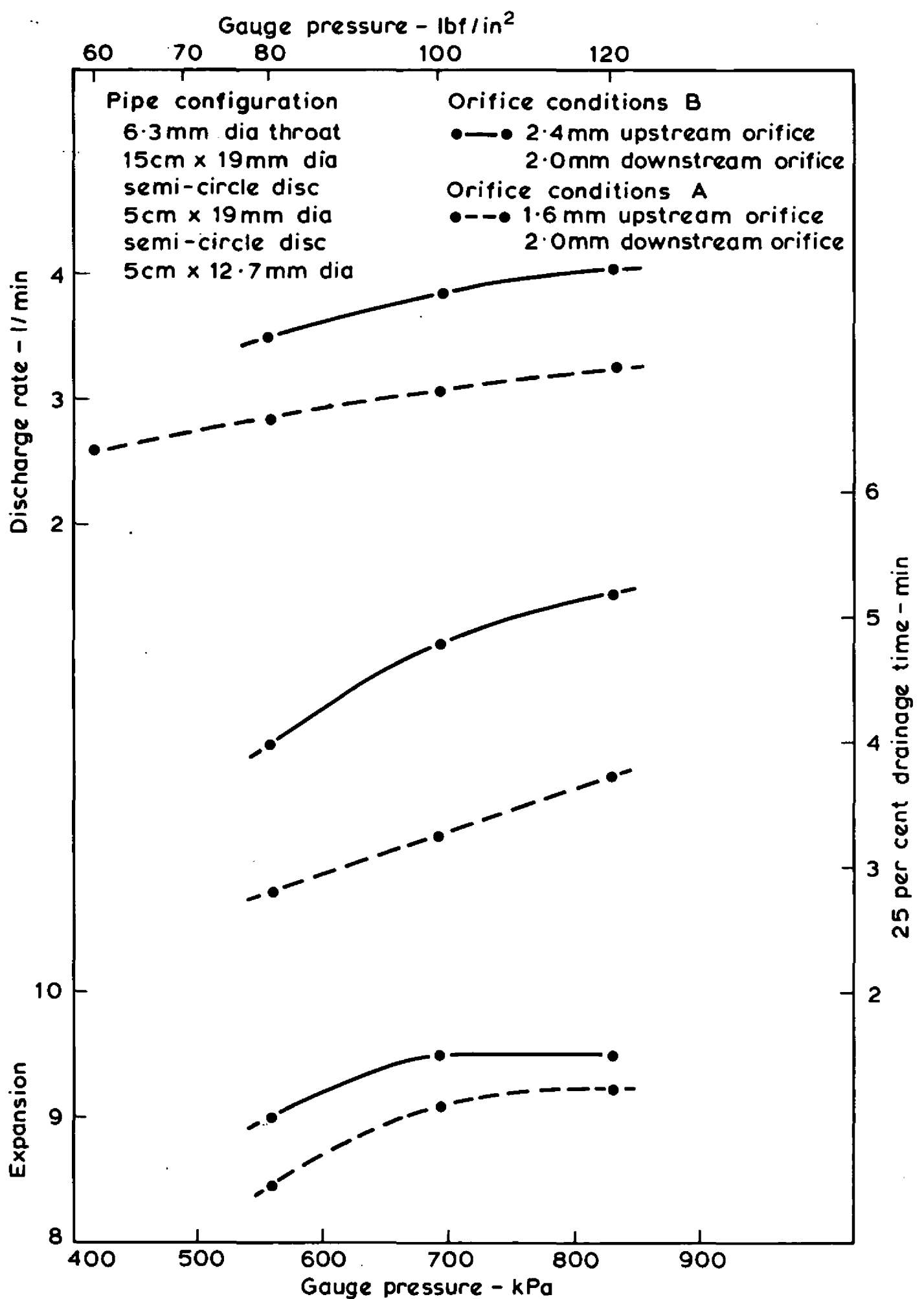


Figure 9 Foam properties with two sizes of upstream orifice using 2 per cent synthetic foam liquid in 19mm dia baffled pipe

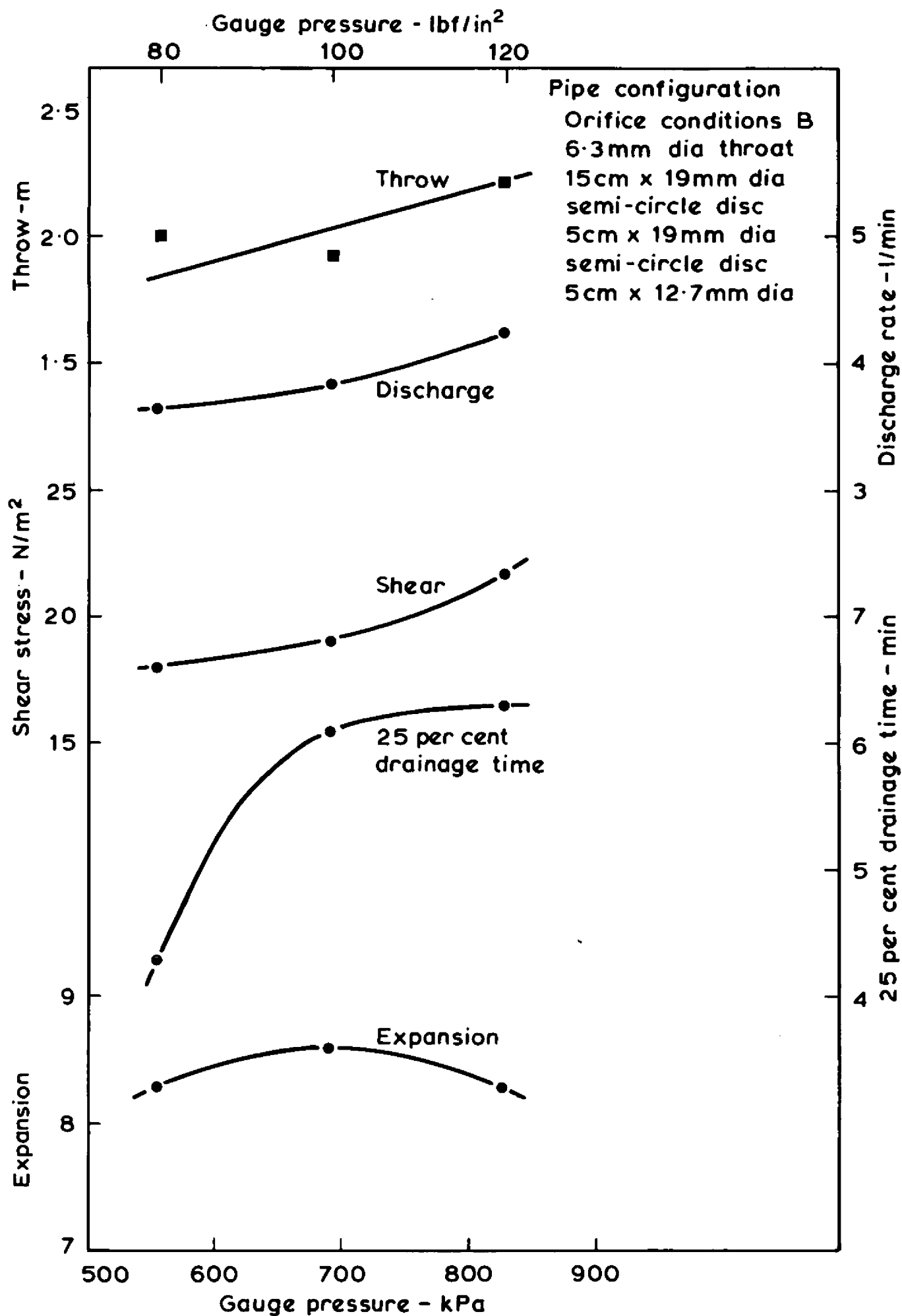


Figure 10 Foam properties in 19mm dia baffled pipe using 4 per cent of protein B2

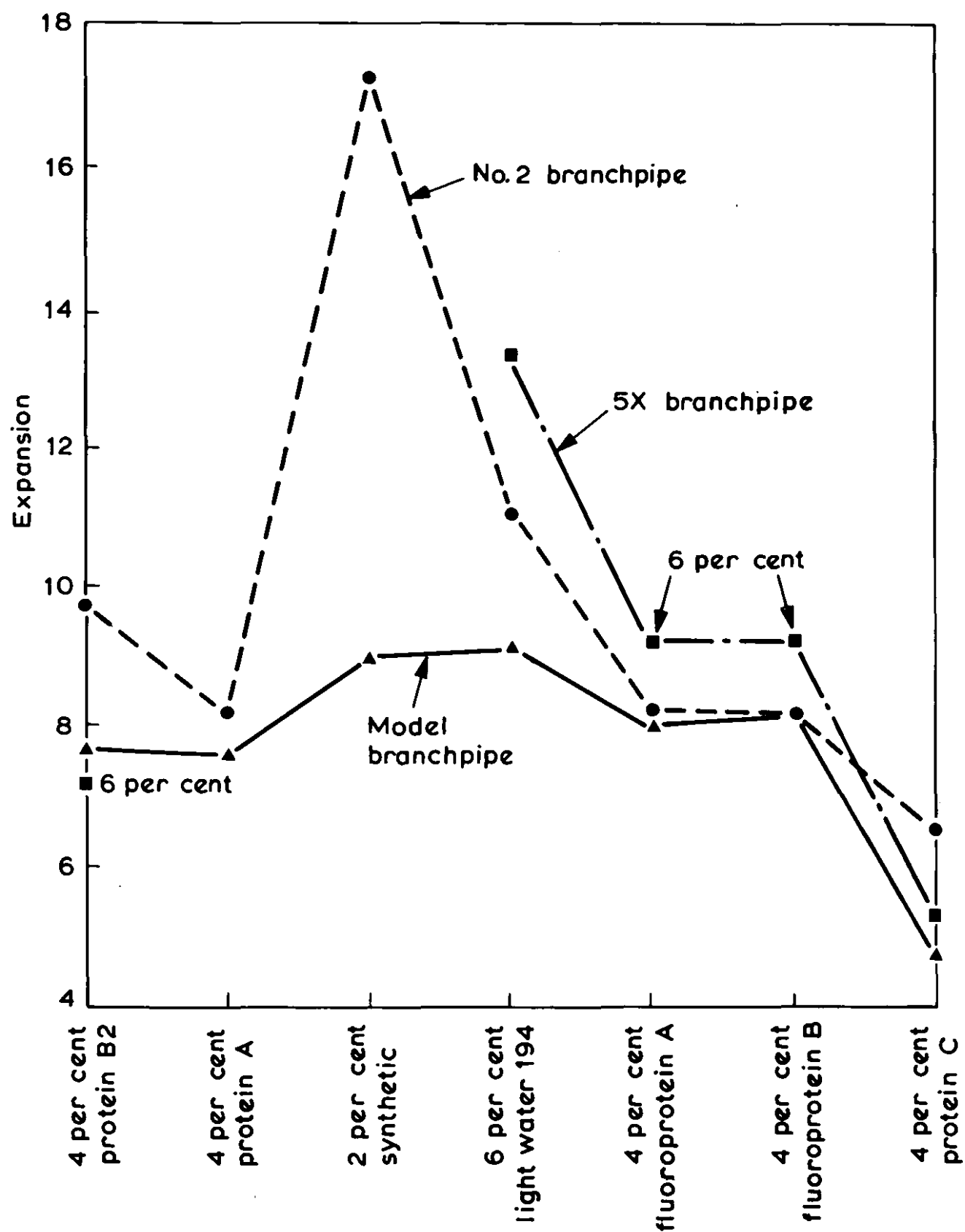


Figure 11 Comparison of expansion between model and two 250 l/min branchpipes with 7 foam liquids

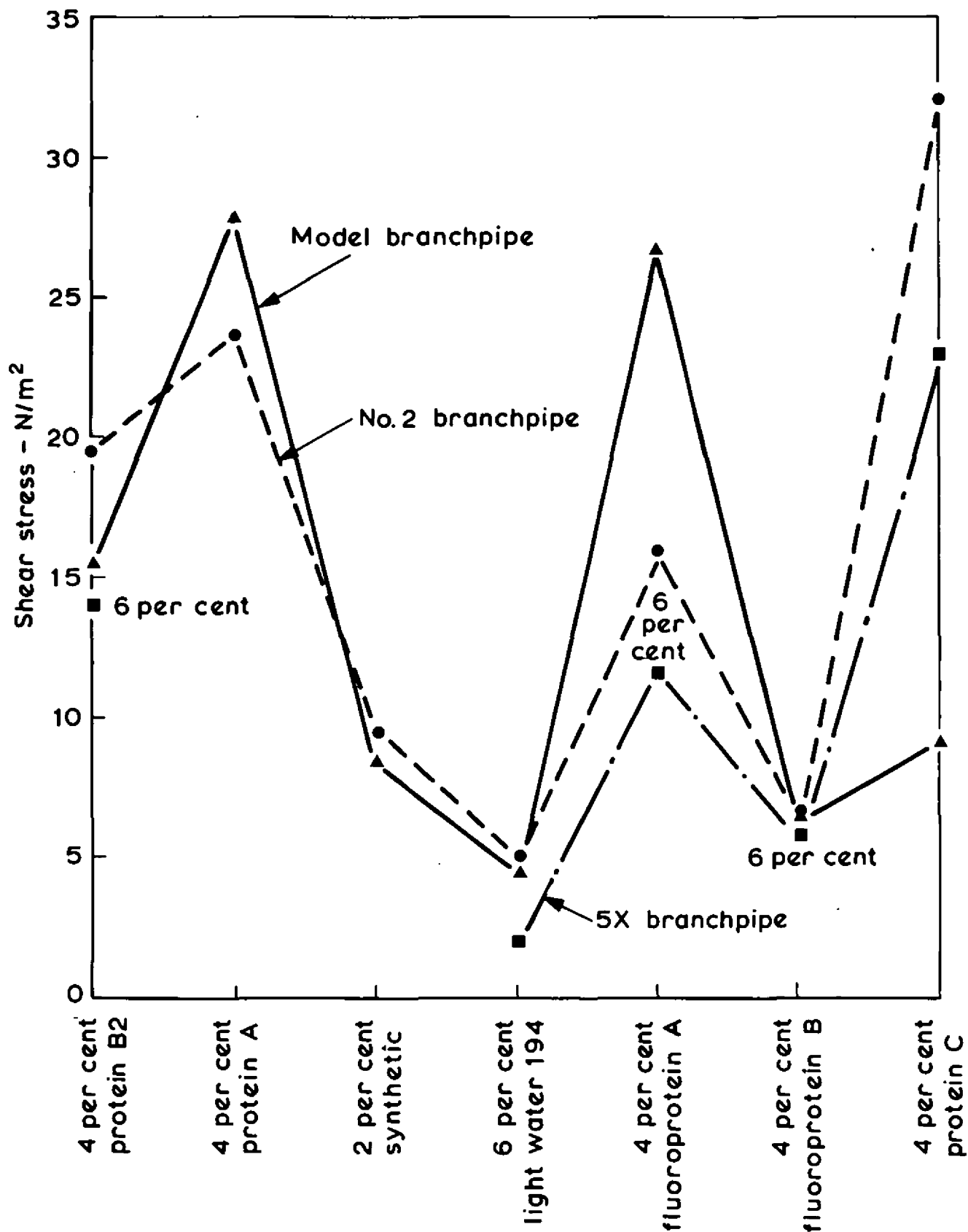


Figure 12 Comparison of shear stresses between model and two 250 l/min branchpipes with 7 foam liquids

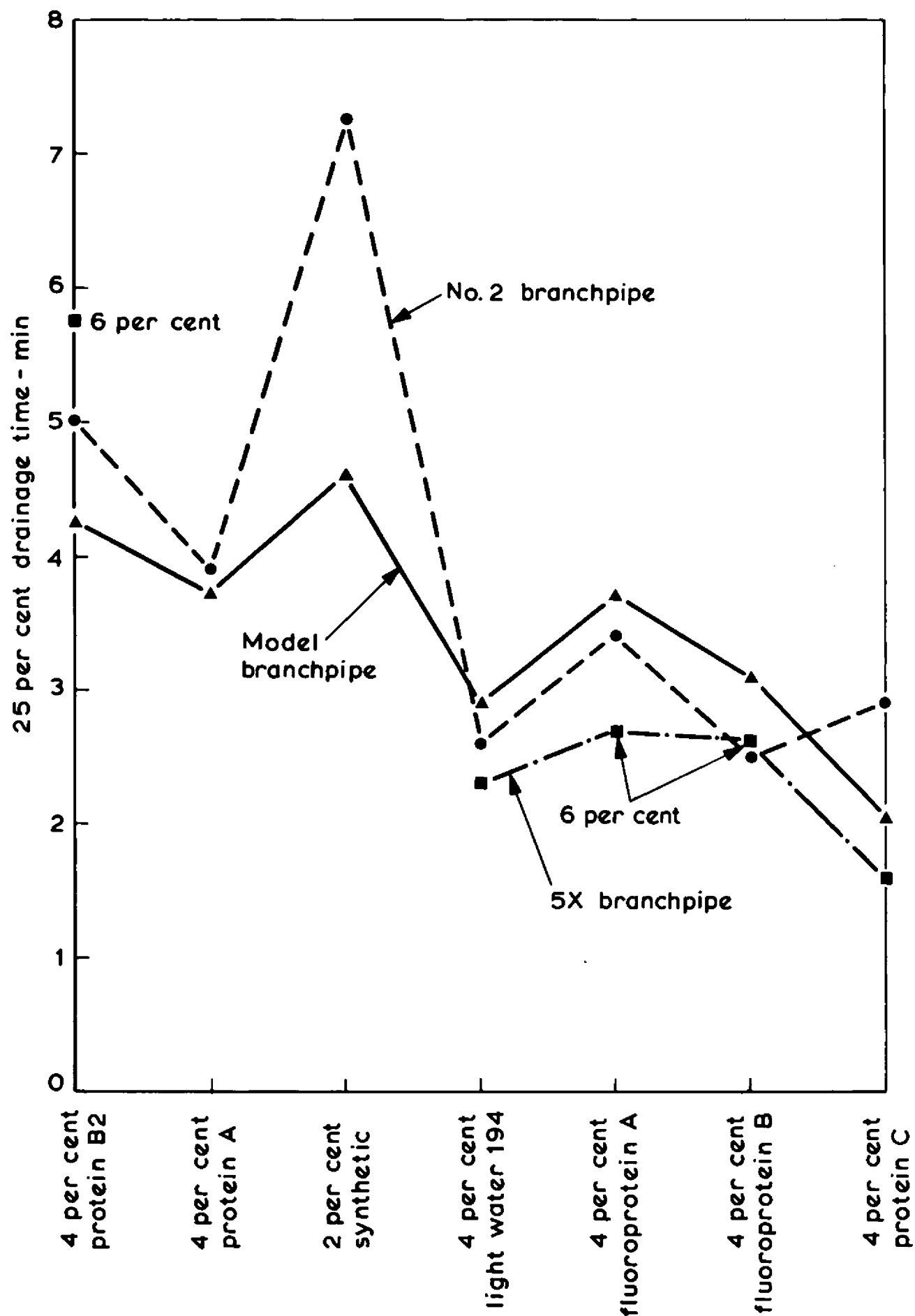


Figure 13 Comparison of 25 per cent drainage times between model and two 250 l/min branchpipes with 7 foam liquids

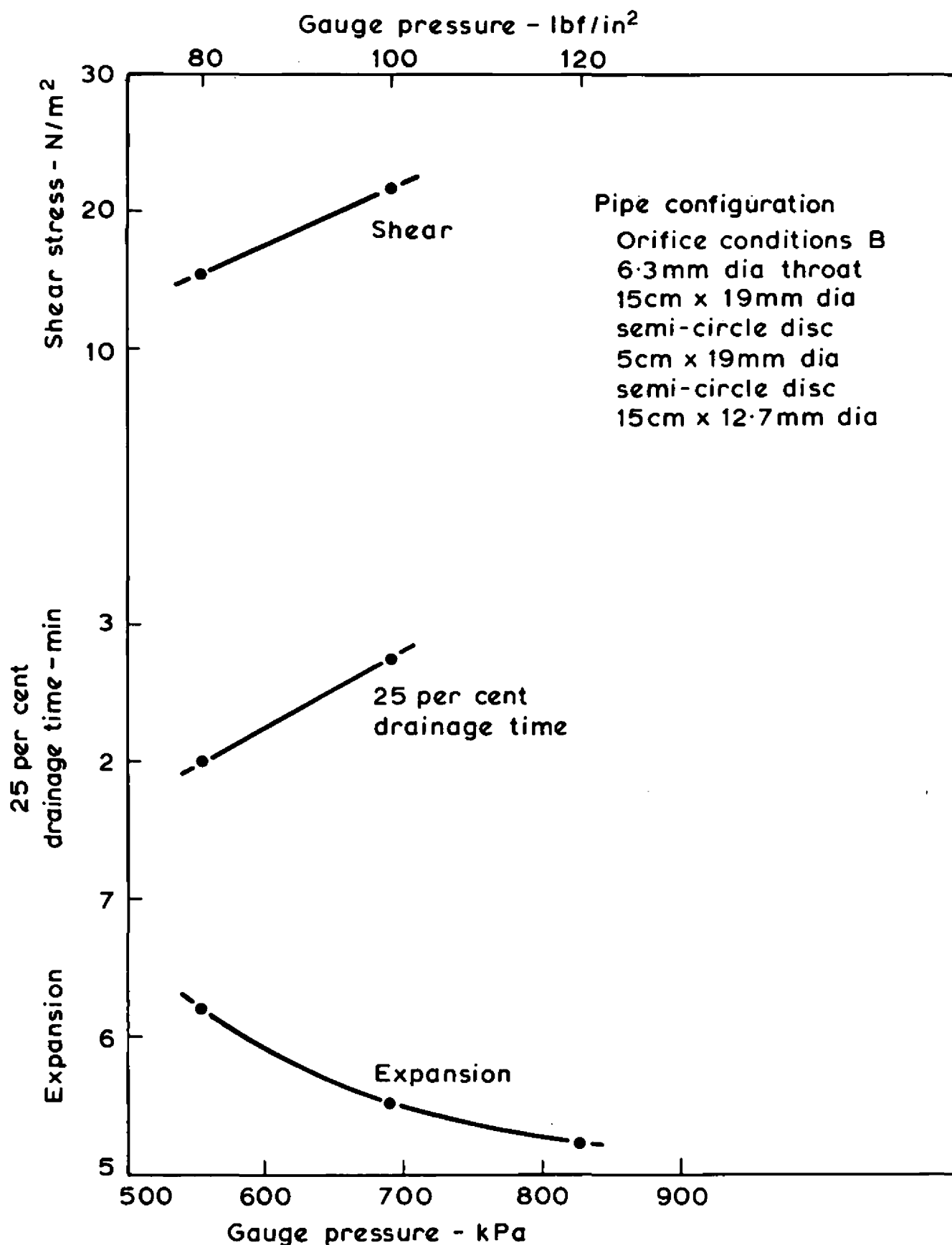


Figure 14 Effect of liquid supply pressure -  
4 per cent protein C



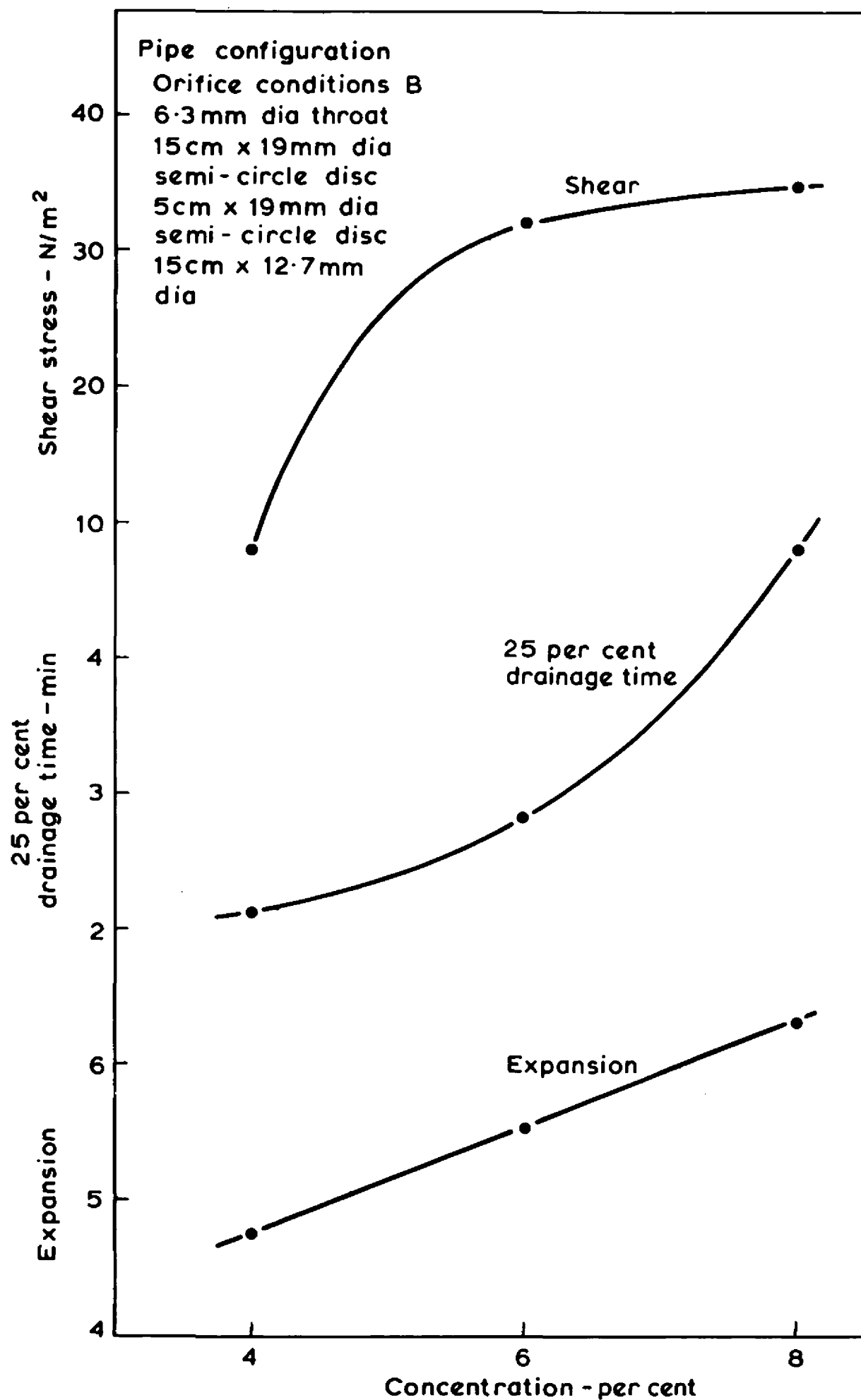


Figure 15 Effect of concentration of protein C - gauge pressure 690kPa (100 lbf/in²)

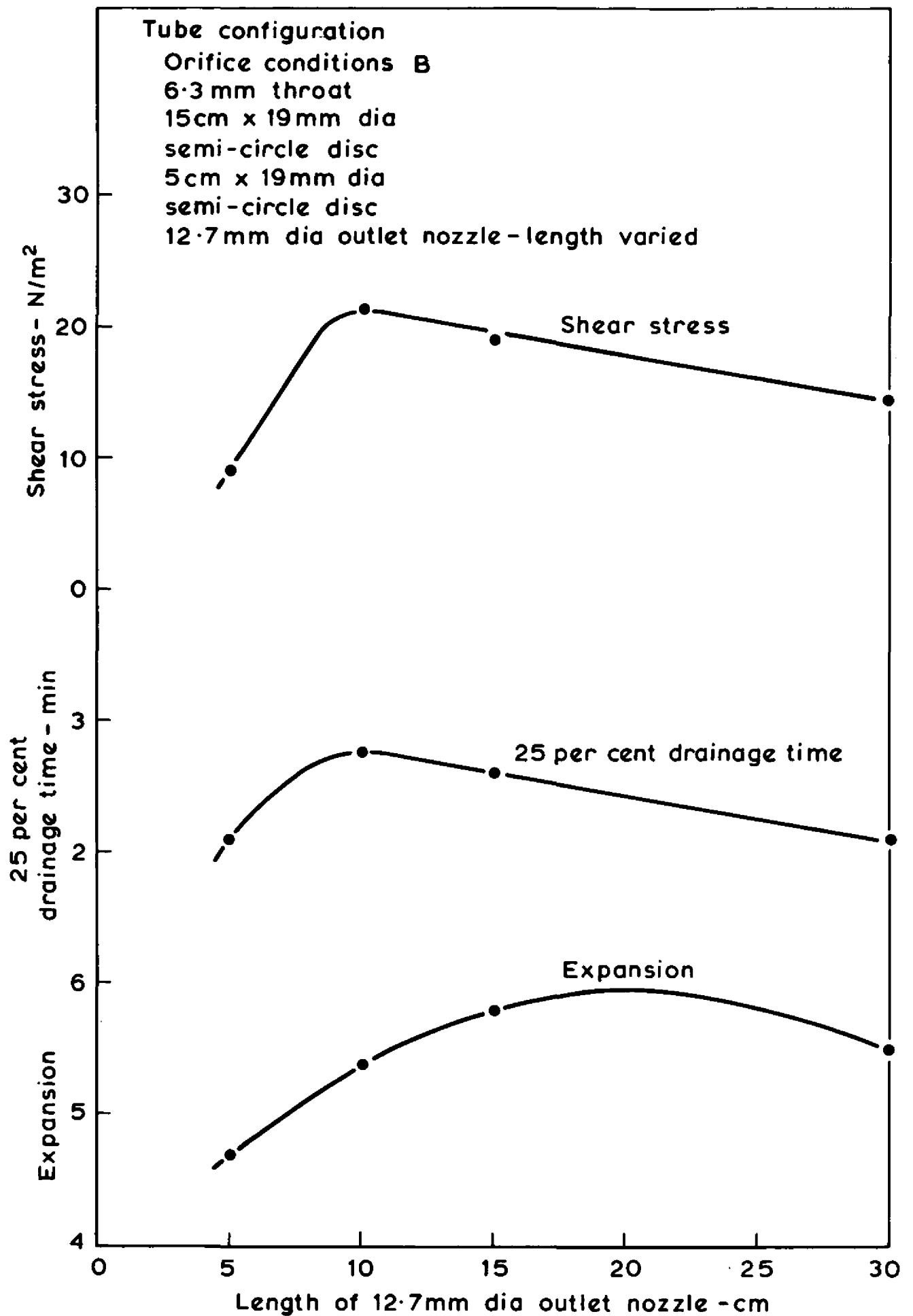


Figure 16 Foam properties with 4 per cent protein C:  
gauge pressure 690 kPa (100 lbf/in<sup>2</sup>) and  
various lengths of 12.7mm dia outlet nozzle

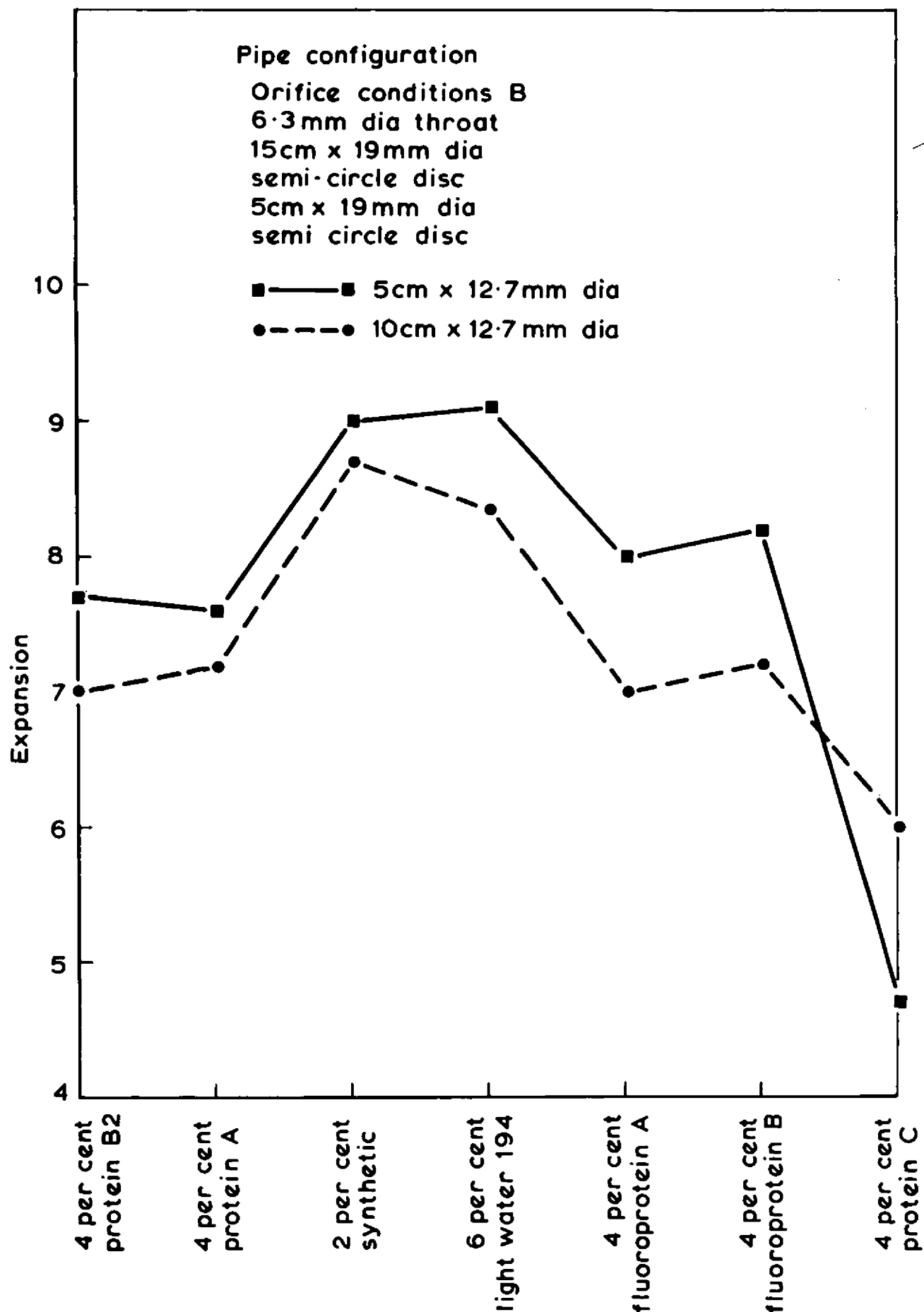


Figure 17 Expansions of seven foams from 19mm dia baffled pipe using two pipe outlets

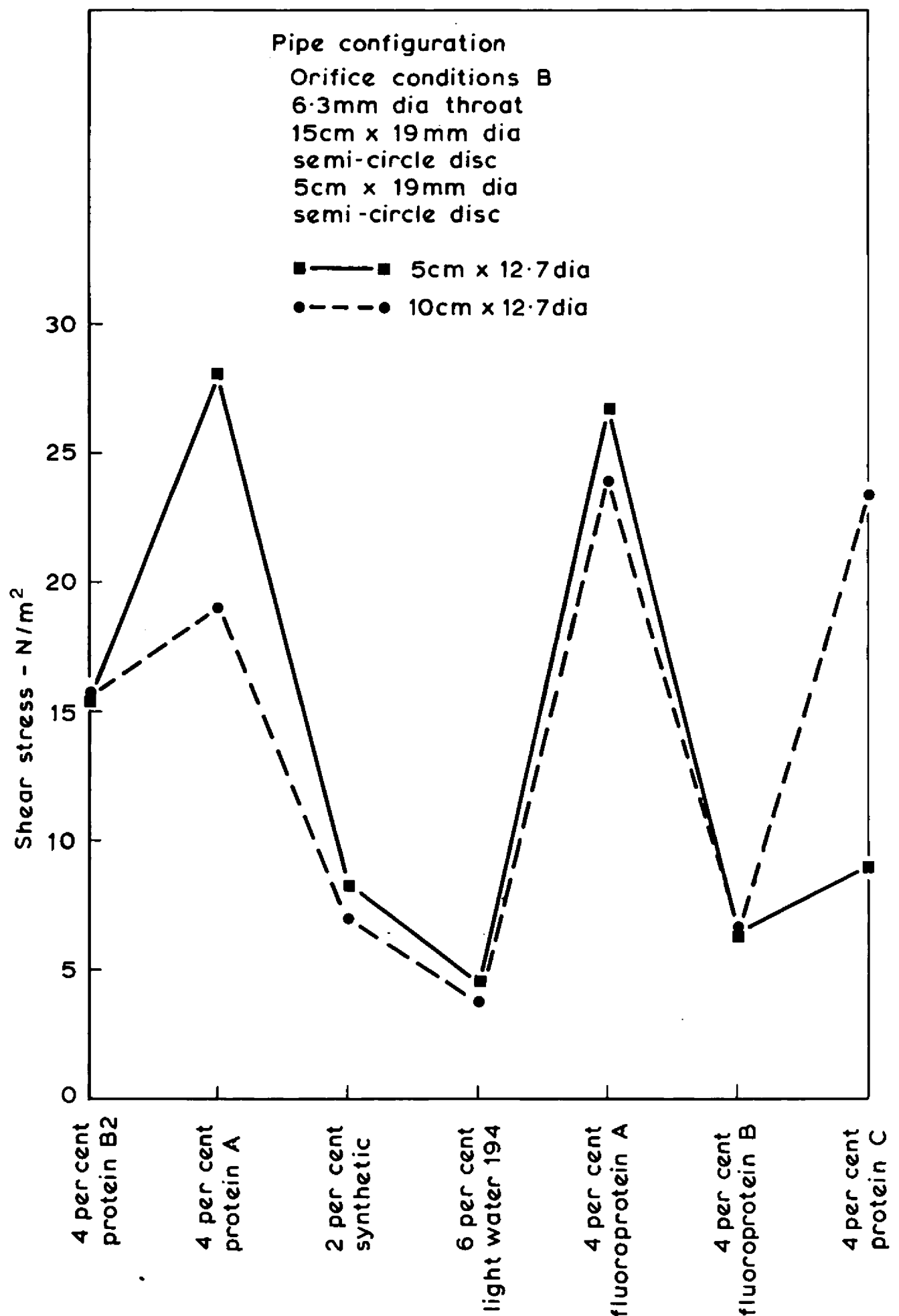


Figure 18 Shear stresses of seven foams from 19mm dia baffled pipe using two pipe outlets

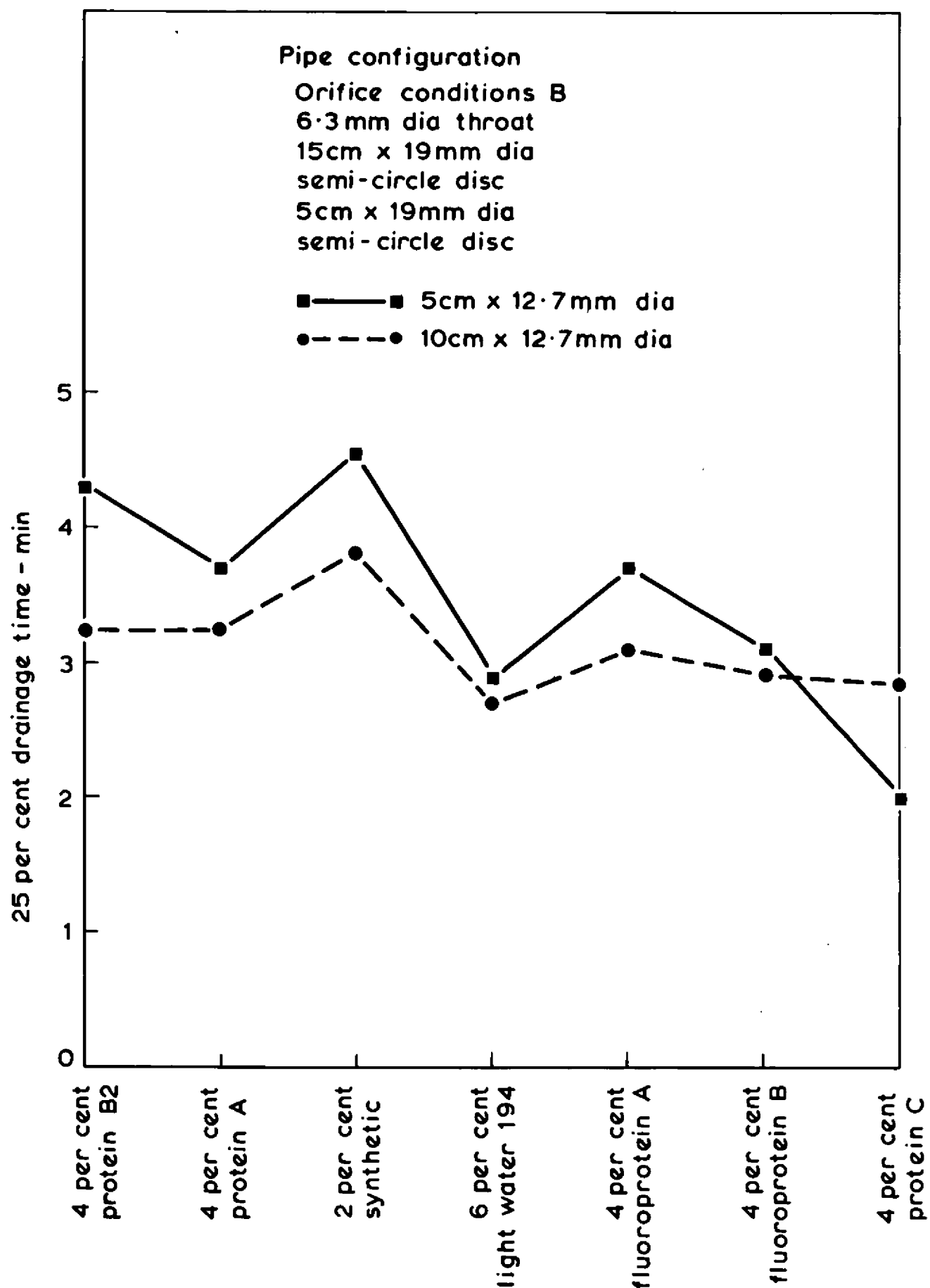


Figure 19 Drainage times for seven foams from 19 mm dia baffled pipe using two pipe outlets

Figure 20 Preferred design of model branchpipe

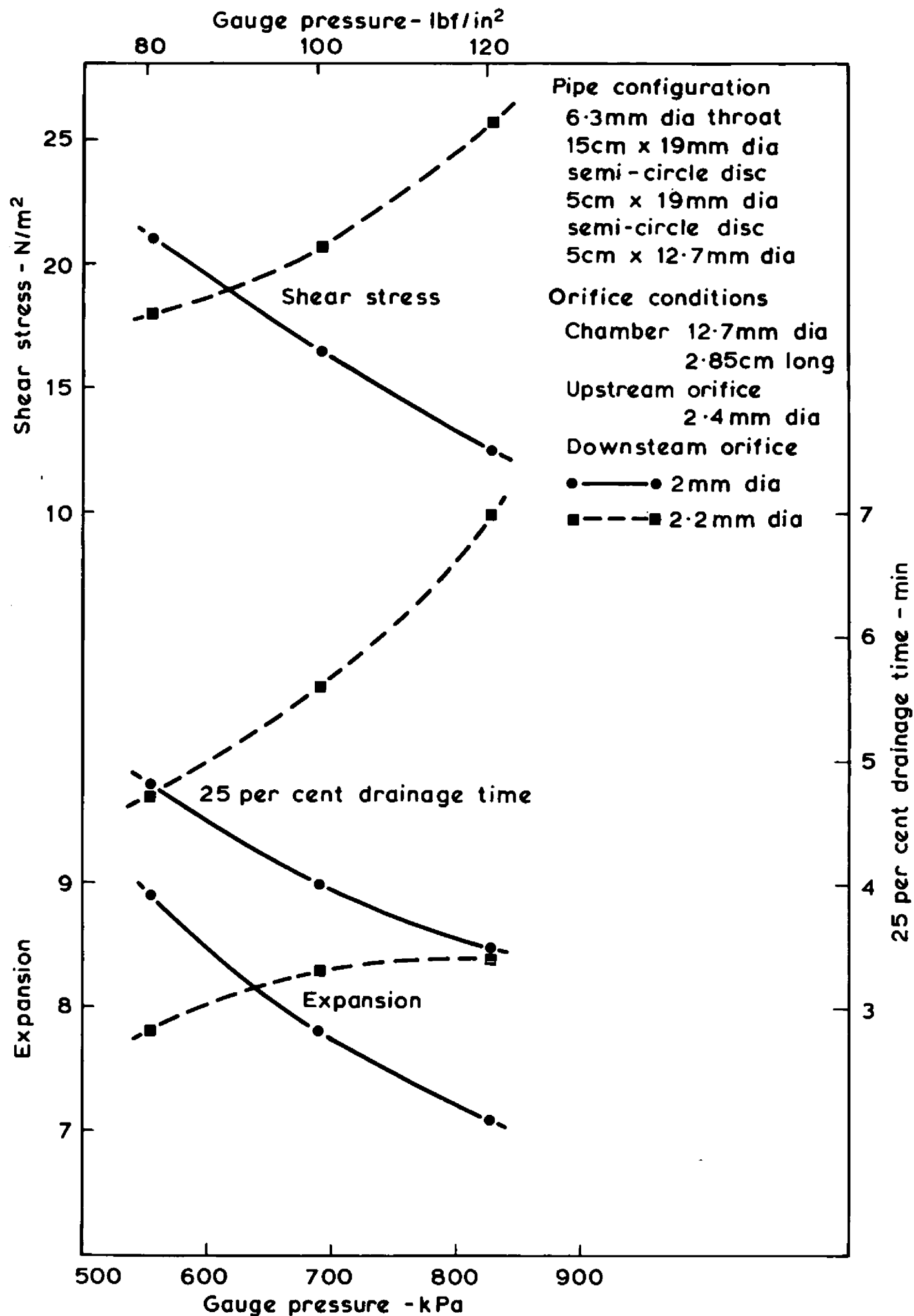


Figure 21 Foam properties from 19mm dia baffled pipe with two downstream orifice sizes and 4 per cent protein B2

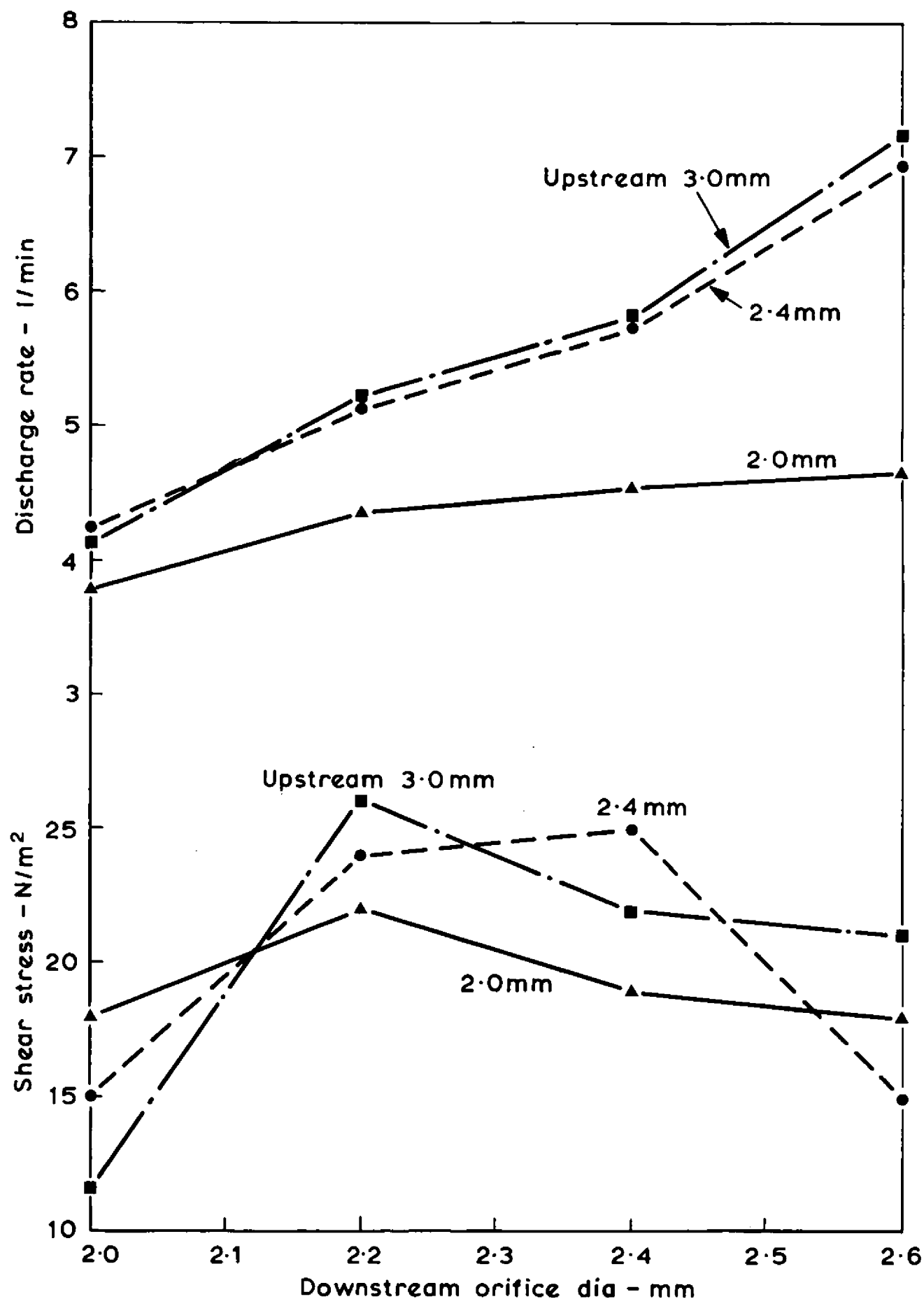


Figure 22 Foam properties from 19mm dia baffled pipe with various upstream and downstream orifices: 4 per cent protein B2: gauge pressure 690kPa (100lbf/in<sup>2</sup>)



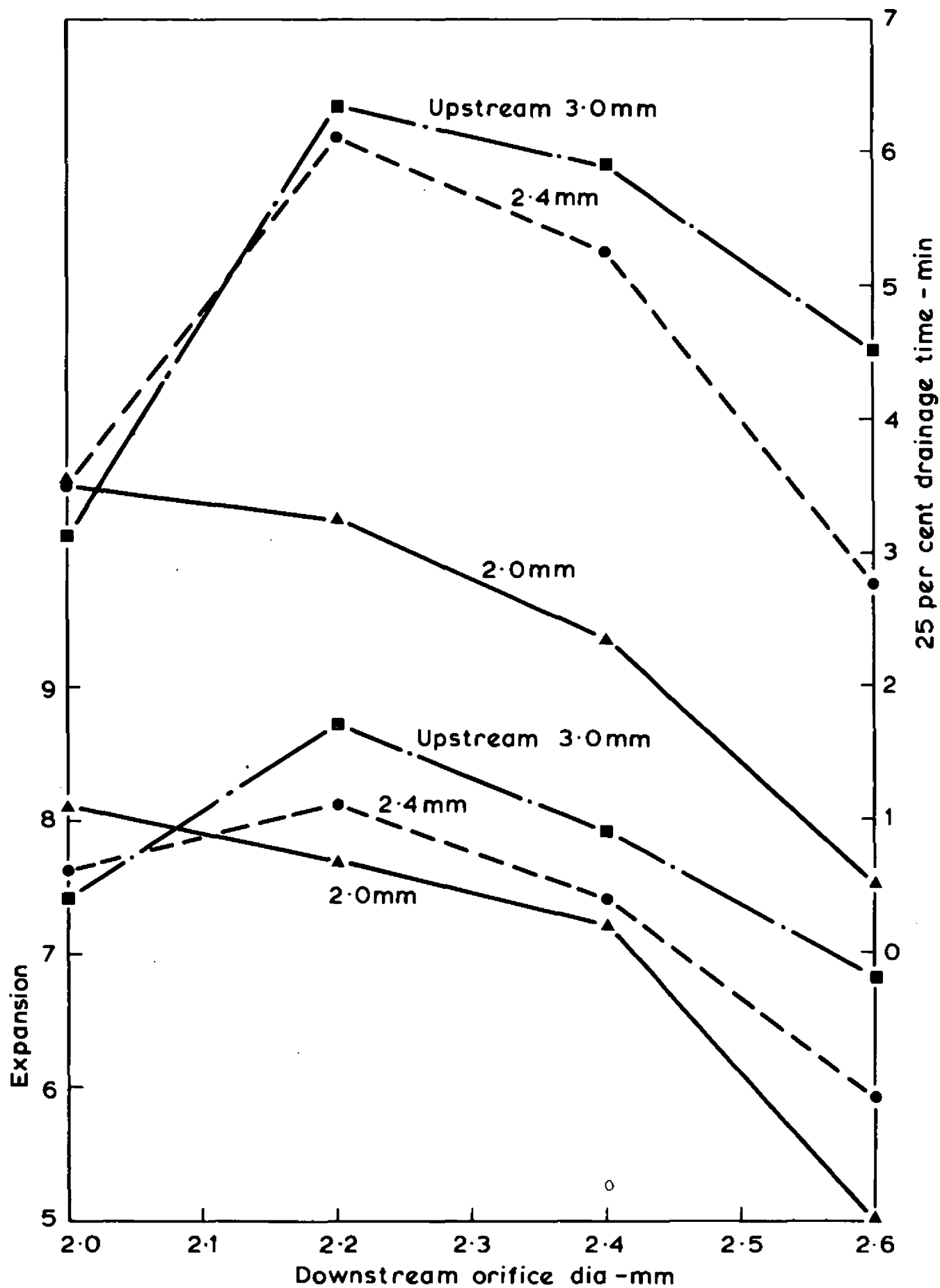


Figure 23 Foam properties from 19mm dia baffled pipe with various upstream and downstream orifices: 4 per cent protein B2: gauge pressure 690k Pa (100 lbf / in<sup>2</sup>)

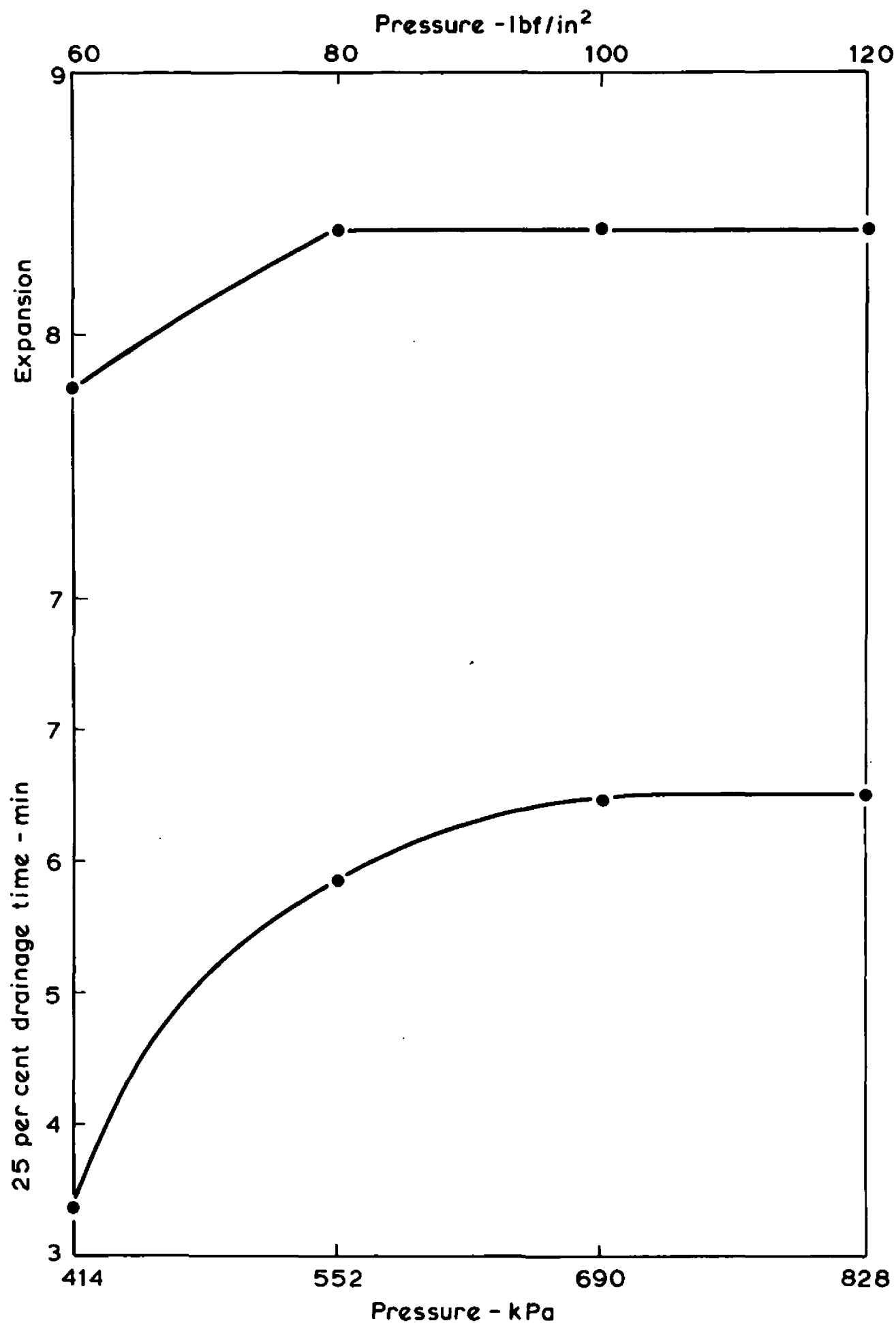


Figure 24 Foam properties from preferred model with 4 per cent protein B2

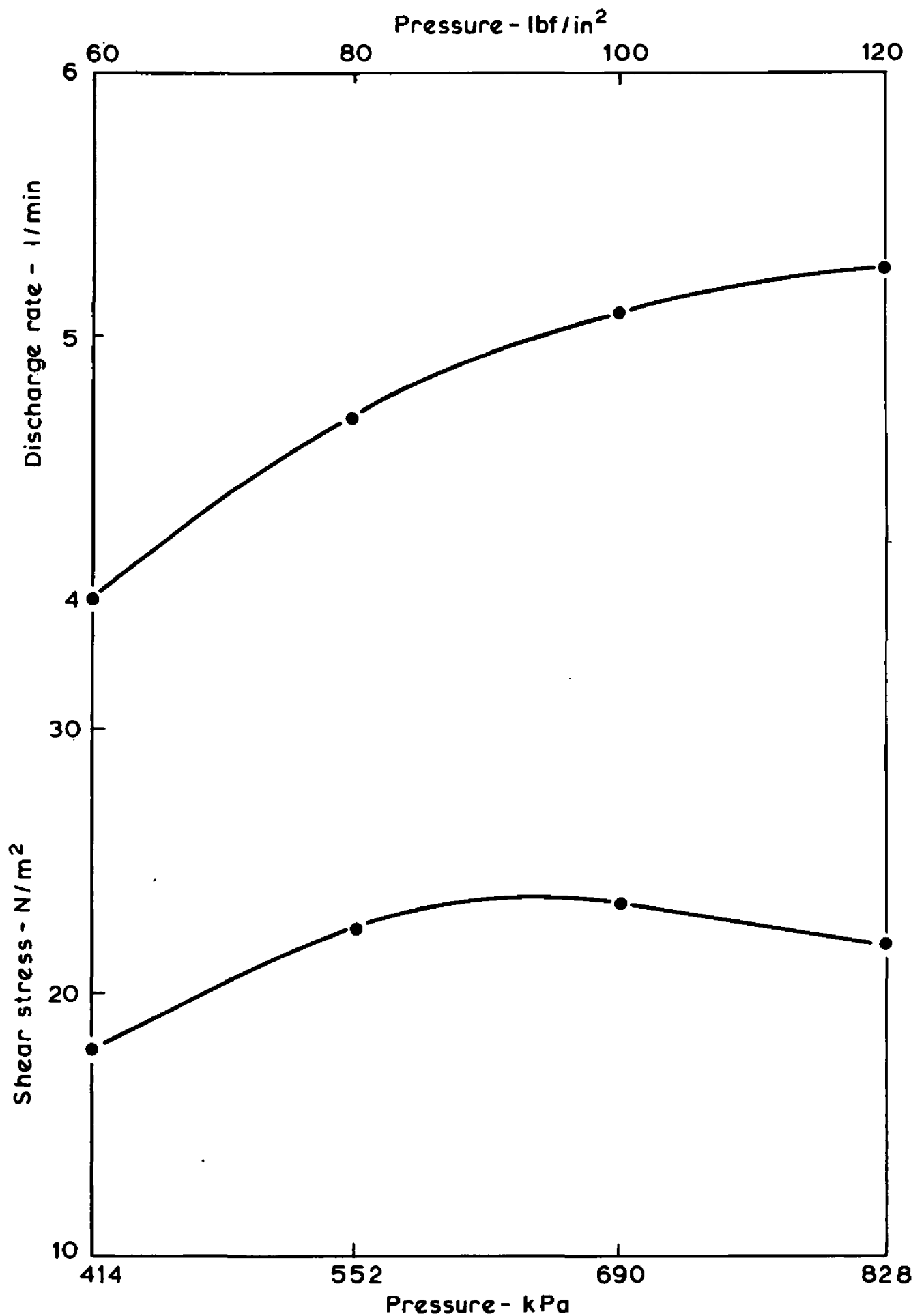


Figure 25 Foam properties from preferred model with 4 per cent protein B2

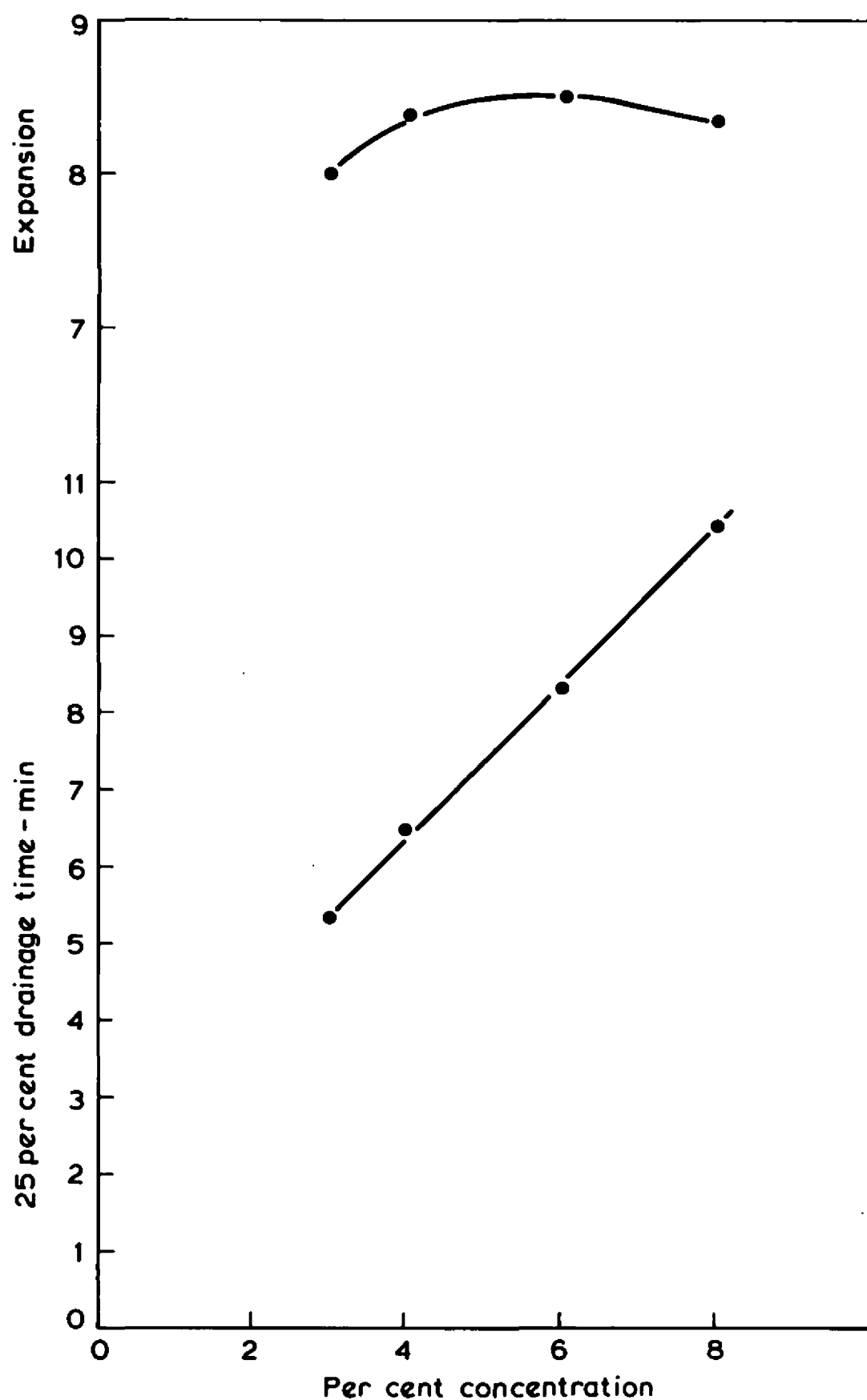


Figure 26 Foam properties from preferred model at 690 kPa and various concentrations of protein B2

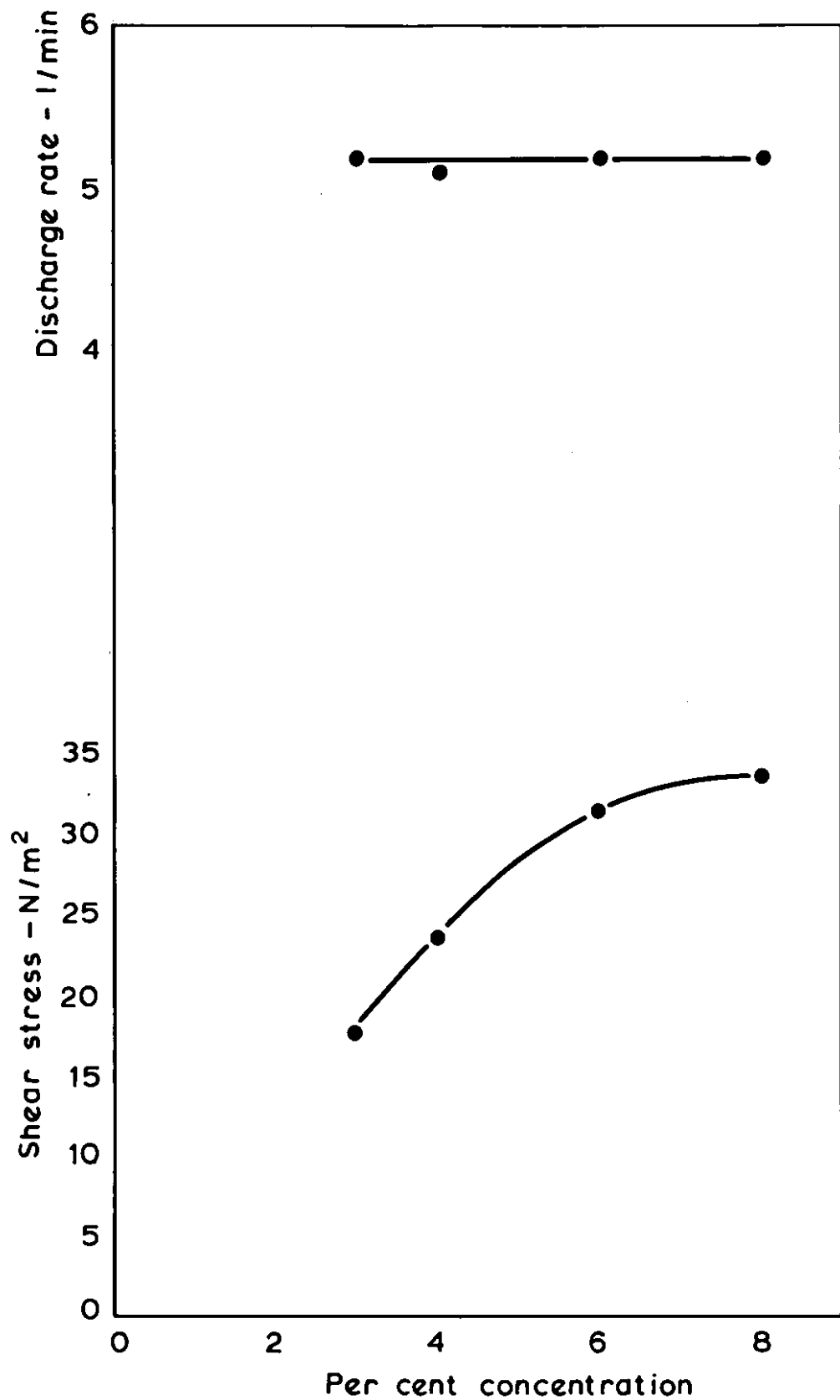


Figure 27 Foam properties from preferred model at 690 kPa and various concentrations of protein B2

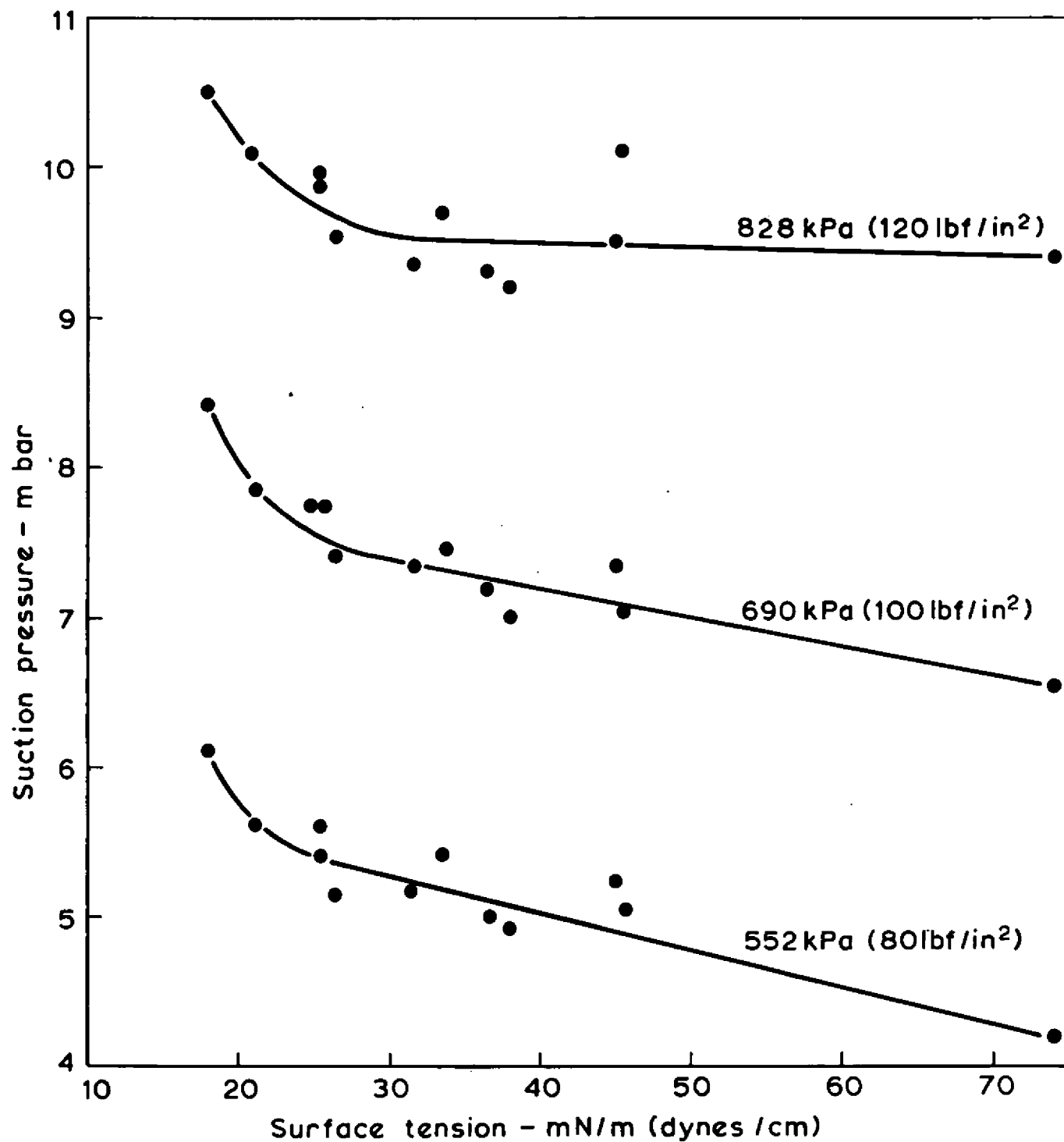


Figure 28 Suction at air inlet to branch pipe with foam liquids of different surface tensions at three liquid supply pressures

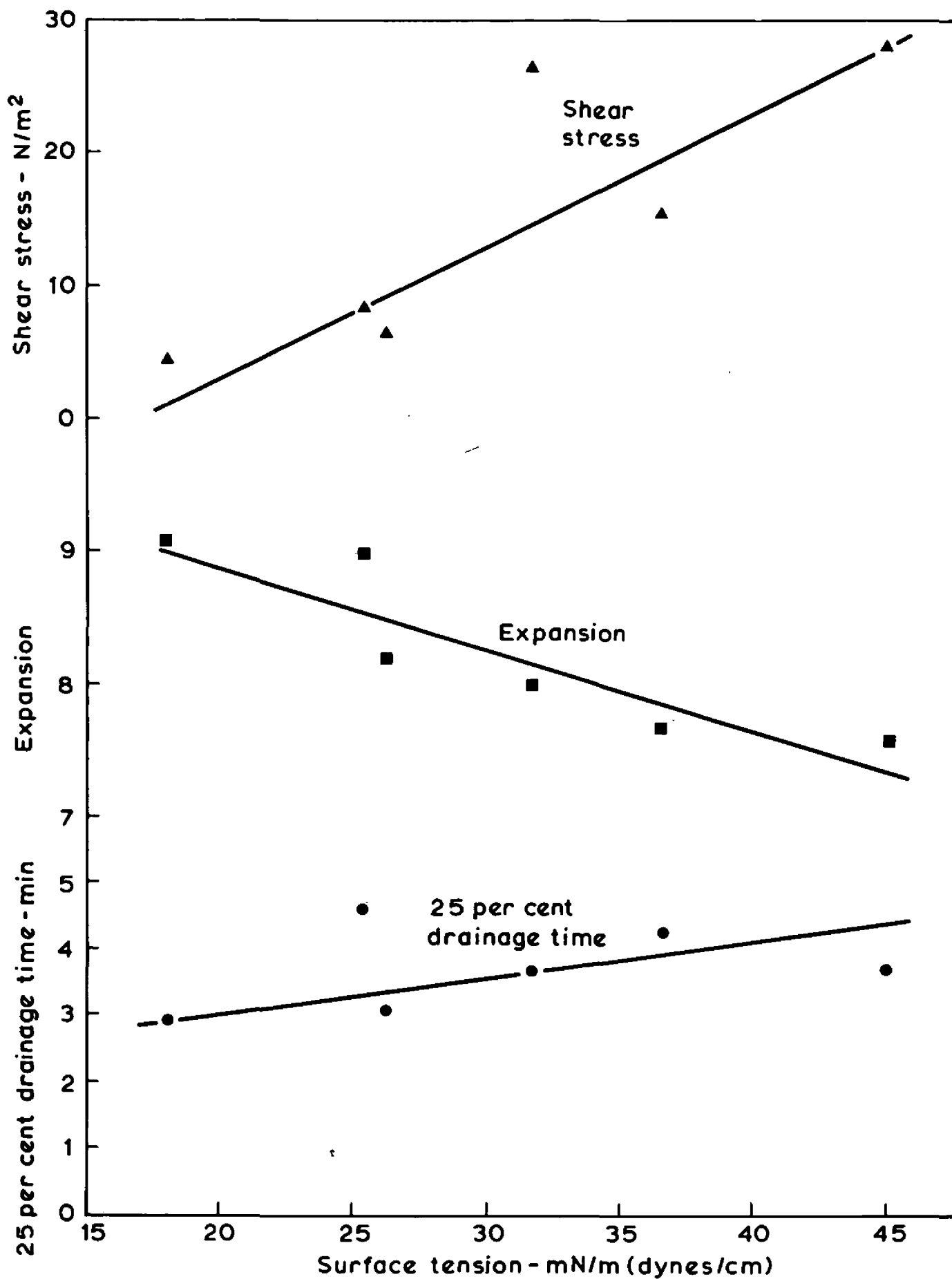


Figure 29 Foam properties from 19mm dia baffled pipe - various foam liquids with different surface tensions

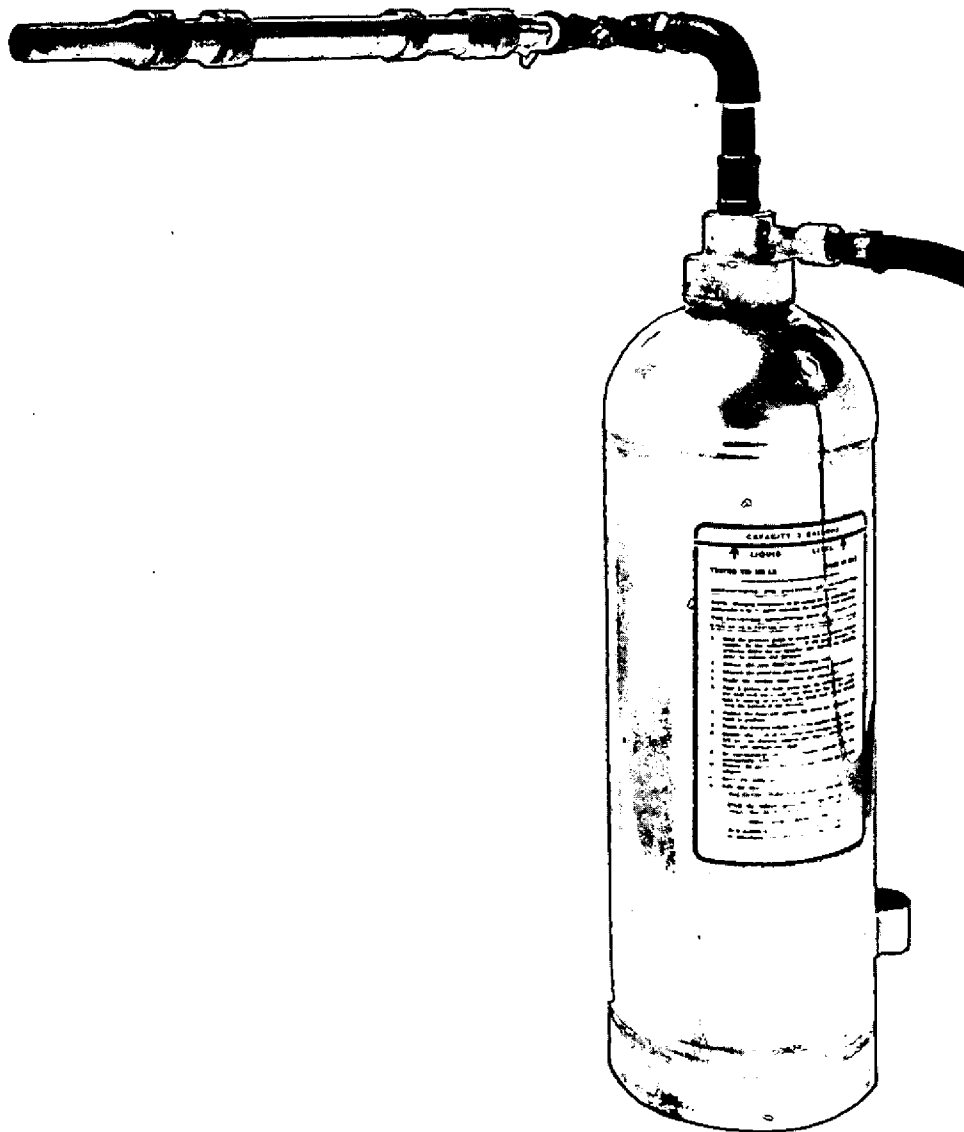


FIG.30 PHOTOGRAPH SHOWING MODEL BRANCHPIPE  
ARRANGED ON EXTINGUISHER BODY WITH  
CONNECTING AIR LINE





